The Future of Banking 3

By Patrick Bolton, Marcin Kacperczyk, Harrison Hong and Xavier Vives

Resilience of the Financial System to Natural Disasters

CEPR

IESE Business School University of Navarra Banking Initiative

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The views expressed in this report are those of the authors and should not be taken to represent any of the institutions with which they are or have been affiliated, or the individuals mentioned above.

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Beatrice Weder di Mauro, Centre for Economic Policy Research
Xavier Vives, IESE Business School
Pablo Hernández de Cos, Banco de España

15:30 **Natural Disasters, Climate Change, and Central Banks**
Patrick Bolton, Columbia University
Discussant 1: Sylvie Goulard, Banque de France
Discussant 2: Sabine Mauderer, Deutsche Bundesbank
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16:45 Break

17:00 **Do Asset Managers Respond to Natural Disasters?**
Marcin Kacperczyk, Imperial College London
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Xavier Vives, IESE Business School

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List of conference participants

Xabier Barriola	PhD Student, IESE, Spain
Antonio Basagoiti	Chairman of Fundación Eugenio Rodríguez Pascual, Senior Advisor Kearney, Fundación Santander, Spain
Charles Bean	Professor, Department of Economics, London School of Economics, United Kingdom
Thorsten Beck	Professor of Banking & Finance, Cass Business School, United Kingdom
Agathe Blanchard	French Treasury, France
Patrick Bolton	Professor of Business, Finance & Economics, Columbia University, United States
Jordi Canals	Professor, Department of Strategic Management and Economics, IESE, Spain
Estelle Cantillon	FNRS Research Director, Université Libre de Bruxelles, Belgium
Elena Carletti	Full Professor, Department of Finance, Bocconi University, Italy
Stijn Claessens	Head of Financial Stability Policy and Deputy Head of the Monetary and Economic Department, Bank for International Settlements, Switzerland
Jean-Pierre Danthine	PSE Professor, Co-Director Collège du Management de l'EPFL, France
Pablo Hernández de Cos	Governor of Banco de España and Chairman of the Basel Committee on Banking Supervision, Spain
Charles Donovan	Executive Director of the Centre for Climate Finance and Investment, Imperial College, United Kingdom
Miguel Duro	Assistant Professor, Department of Accounting and Control, IESE, Spain
Robert Eccles	Visiting Professor of Management Practice, Saïd Business School University of Oxford, United Kingdom
Robert F. Engle	Professor of Finance, New York University Stern School of Business, United States
Nuno Fernandes	Professor, Department of Financial Management, IESE, Spain
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Caroline Flammer	Associate Professor of Strategy & Innovation, Boston University, United States

Xavier Freixas	Emeritus Professor, Universitat Pompeu Fabra, Spain
Paolo Fulghieri	Professor of Finance, UNC Kenan-Flagler Business School, University of North Carolina, United States
Teresa Garcia-Mila	Professor, Department of Economics, Universitat Pompeu Fabra and Director, Barcelona GSE, Spain
Thomas Gehrig	Chair in Finance, Department of Finance, University of Vienna, Austria
Francisco Gibert	Partner, KPMG, Spain
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Philipp Hartmann	Deputy Director General, European Central Bank, Germany
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Harrison Hong	Professor of Economics, Columbia University, United States
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Marcin Kacperczyk	Professor of Finance, Imperial College London, United Kingdom
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Carmen Matutes Juan	Waveform Investments, Spain
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Alex Michaelides	Professor of Finance, Imperial College Business School, United Kingdom
Amparo Moraleda	CaixaBank Independent Director
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Giovanna Nicodano	Professor of Financial Economics, Università di Torino and Collegio Carlo Alberto, Italy
Tessa Ogden	Chief Executive Officer, CEPR, United Kingdom
Gaizka Ormazabal	Associate Professor, Department of Accounting and Control, IESE, Spain
Lubos Pastor	Charles P. McQuaid Professor of Finance, University of Chicago, United States
Fernando Peñalva	Professor, Department of Accounting and Control, IESE, Spain
Juan Pérez-Campanero	Managing Director, Santander Global Banking and Markets, Spain
Andrew Pitt	Global Head of Research, Citi, United Kingdom
Lucrezia Reichlin	Full Professor of Economics, London Business School, United Kingdom
Rafael Repullo	Professor of Economics and Director, CEMFI, Spain
Fernando Restoy	Chairman of the Financial Stability Institute, Bank for International Settlements,
Hélène Rey	Professor of Economics, London Business School, United Kingdom
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Jordi Salvador	Manager, Public-Private Sector Research Center, IESE, Spain
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Enrique Schroth	Professor of Finance, EDHEC Business School, France
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Josep Soler	Director, Institut d'Estudis Financers, Spain
Javier Suarez	Professor of Finance, CEMFI, Spain
Giorgia Trupia	Research Assistant, IESE, Spain
Francisco Uria	Senior Partner, KPMG, Spain
Koro Usarraga	2005 KP Inversiones SL, Spain
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Xavier Vives	Professor, Department of Economics and Finance, IESE, Spain
Ernst-Ludwig von Thadden	Professor of Microeconomics and Finance, University of Mannheim, Germany
Beatrice Weder di Mauro	President, CEPR, United Kingdom
Zhiqiang Ye	PhD Student, IESE, Spain

Foreword

This is the third report in the series on *The Future of Banking*, part of the Banking Initiative from the IESE Business School that was launched in October 2018 and is supported by Citi.

The goal of the IESE Banking Initiative is to establish a group of first-rate researchers to study new developments in banking and financial markets, paying particular attention to regulation and competition policy and to the impact on business banking models and the performance of markets. It aims to promote a rigorous and informed dialogue on current issues in the fields of banking and financial markets amongst academics, regulators, private sector companies and civil society.

The first report assessed the regulatory reform of the banking system after the Great Recession induced by the global financial crisis (GFC) of 2008-2009. It stated then that the next global crisis might have different origins, possibly in entities that perform the functions of banks but are outside of the regulatory perimeter, with operational risk on the rise, or in an emerging market where regulation could well be different from the reformed patterns of the West. It concluded that the system had been made more resilient but that further work remained to be done. The Covid-19-induced crisis has tested the regulatory reform put in place after the GFC that was analysed in the first report.

The second report addressed the changes in the business models of banks and identified that the challenges that banks faced in the pre-Covid-19 world – mainly low interest rates and digital disruption – will be made more severe in the post-Covid-19 world. Banks have had to deal with an increase in non-performing loans, albeit with temporary relief from strict regulation and with massive liquidity help from central banks. This has accelerated restructuring in the sector.

The third report studies in what ways climate and natural disaster risk is different from other, more familiar forms of financial and economic risk, and how banks, asset managers and central banks are beginning to grapple with these risks. Covid-19 has made us aware of the potentially devastating effect of natural disasters and provides a pointer to the effects that climate change may induce. The pandemic raises the question of how resilient the financial system is to natural disasters. At the same time, the Covid-19 crisis provides a large-scale natural experiment to address this question, and puts natural disasters, whether they be pandemics or climate catastrophes, on the agenda of private institutions, bank regulators and central banks.

The report was produced following the conference “Resilience of the Financial System to Natural Disasters” which was held online on 17-18 March 2021. The conference programme, together with the comments of the six discussants, are included in this report, as well as the introductory speech by the Governor of the Bank of Spain, Pablo Hernández de Cos. The team of authors was brought together and is led by Xavier Vives.

The Banking Initiative has benefitted from the keen support of the Dean of IESE, Franz Heukamp, and the former Dean, Jordi Canals. CEPR and IESE are very grateful to the authors and discussants for their efforts in preparing this report, as well as to the conference attendees for their perceptive comments. We are also grateful to Sachiko Ando and Carlota Monner for their extremely efficient organisation of the conference as well as providing support for the report, and to Anil Shamdasani for his unstinting and patient work in publishing the report.

The views expressed in the report are those exclusively of its authors and do not represent those of CEPR, which takes no institutional positions on economic policy matters. CEPR and IESE are delighted to provide a platform for an exchange of views on this topic.

Tessa Ogden	Xavier Vives
Chief Executive Officer, CEPR	Director, IESE Banking Initiative

May 2021

Executive summary

The Covid-19 crisis and the subsequent downturn have reinforced the need to evaluate and address highly disruptive environment-related events as well as the strategic importance of sustainable finance in the upcoming years. The pandemic may serve as an experimental study to learn about climate change mitigation policies. Similar to the coronavirus outbreak, climate change involves the realisation of tail-related events manifested as global externalities that pose systemic financial risk, involve market failures, and call for supportive public intervention and international coordination.

Several questions arise: *What are the risks associated with climate change and the appropriate risk-management tools to address them? What is the role of central banking in the transition to a green economy? How do the systemic nature of natural disasters and the potential persistence of shocks affect diversification and hedging strategies of financial intermediaries? What commitments in sustainable finance mandates are needed to meet net-zero emissions targets?* The aim of this report is to assess how resilient the financial system is to natural disasters and what can be done to improve this resiliency.

Natural disasters are a major source of systemic risks, and finance has to play a major role in the prevention and taming of those risks. Climate-related events are a representative example of natural disasters that involve several externalities, such as CO2 emissions, R&D spillovers and learning curve effects. Fighting climate change will require the combination of public intervention and private sector mitigation strategies to price and hedge the long-term implications of climate-related events. Carbon abatement proposals include net-zero commitments made by government and companies around the world to decarbonise the economy, and sustainable finance mandates backed by financial intermediaries to incentivise firms' efforts towards decarbonisation.

The report addresses three issues related to the resilience of the financial system to tail events: the reshaping of central bank policies to address climate-related risks (Chapter 2); the role of asset managers in dealing with natural disasters and climate risk (Chapter 3); and mitigation as a form of self-insurance to limit the systemic risks of global warming (Chapter 4).

A first broad message is that central banks can play a proactive role in promoting mitigation policies and coordinating climate risk policies consistent with government mandates, the private sector and civil society. A central bank action focused on the development of forward-looking scenarios and the implementation of climate stress tests might not be sufficient to satisfy their financial stability mandate, since climate change may be a major source of systemic risk.

A second broad message is that asset managers can facilitate the management of climate risk and promote green financing. Although an array of hedging instruments has been developed by the financial industry, natural disasters involve systemic risks that investors cannot fully hedge. Financial markets and asset managers could discipline market participants to stimulate mitigation efforts by the real sector.

A third broad message is that the impact of future climate shocks on stock valuations could be similar to that seen during the Covid-19 pandemic. But climate mitigation investments could also have positive effects on stock valuations and climate risk-management responses similar to those seen with the rapid development of vaccines to combat the pandemic.

Government subsidies and public–private partnerships were instrumental in implementing Covid-19 vaccination programmes and contributed to creating expectations of a fast-arriving vaccine that helped calm global stock prices in March 2020. Due to the presence of externalities, a tax on capital to fund mitigation might be needed to restore efficiency in carbon emissions.

NATURAL DISASTERS, CLIMATE CHANGE AND CENTRAL BANKS

Natural disaster and climate shocks pose a fundamental question for the lender of last resort (LOLR) as a policy response to dampen the financial and economic repercussions from such events. Natural disasters can severely affect economic activity and quickly destabilise financial markets. They can simultaneously trigger a sharp stock market correction, resulting in a major loss of financial wealth, and a spike in demand for liquidity. The complexity of climate risk also includes the effect on societies of a warming planet and how extreme temperatures will give rise to geopolitical risks. From a financial stability perspective, therefore, central banks must include natural disaster risk in their prudential policy frameworks. The policy response to stabilise the financial system, however, should avoid an excessive reliance on central bank backstops. As the expectation of a bailout incites moral hazard in lending and risk taking, LOLR interventions should not become the default intervention to stem a financial crisis.

A first step to manage climate change risk should be an improvement in the measuring and reporting of carbon emissions to foster the disclosure of emissions by companies and financial institutions. Both through supervision and regulation, central banks and bank regulatory agencies can accelerate the reporting of carbon footprints. In line with the net-zero commitments, corporations would be required to report their emissions on an annual basis as well as future projected emissions up to a three-year horizon. Risk cannot be measured through short horizons; it must be addressed through exposures on carbon footprints and by testing the financial consequences of reducing these exposures for the whole financial system. A good approach here is forward-looking scenario building, which allows for a versatile analysis that at the same time cuts through the complexity of making reliable probability assessments.

Another important tool to design the transition path towards a carbon-neutral economy is the implementation of climate stress tests to identify not only the size of climate risk exposures in the banking and insurance sectors, but also the extent to which an orderly transition path, with early action, is feasible. Another general policy direction that is relatively uncontroversial and that is consistent with the conduct of climate stress tests is mandatory disclosure of climate-related risk exposures. Yet, the standardised reporting of physical climate risk exposures is technically challenging and may not be immediately feasible. A priority for the coming years should be to systematise carbon disclosures and to extend disclosure mandates to as many countries as possible. Once carbon emissions and carbon footprints are systematically reported at the firm level, it will be much easier to monitor the year-by-year progress of companies in reducing their emissions and the progress of financial institutions and asset managers in decarbonising their portfolios.

A more difficult and controversial question is whether climate change risk considerations also touch on the conduct of monetary policy and the management of central bank reserves. By applying the neutrality principle, central banks are by default tilted towards assets from companies associated with high carbon emissions, whether directly or indirectly. When it comes to collateral frameworks and reserve asset management, central banks need to align their policies with the broader net-zero commitments of their countries.

ASSET MANAGERS' RESPONSE TO NATURAL DISASTERS

The asset management sector has played a crucial intermediary role in financial markets, but there are some concerns about the capacity of the financial sector to hedge the underlying long-term risks of catastrophic events. While large investors, and in particular universal owners such as large pension funds, are aware of the danger posed by climate-related systemic risk, there is a role for markets to issue assets with more complete state contingencies that deal with such long-term risks.

The main challenge is that traditional models of asset pricing are not suitable to test whether climate risk is fairly priced. The systemic nature of natural disasters complicates the hedging activity for financial players because of the lack of effective risk-sharing. First, there is a significant estimation error as tail shocks are rare events. Second, climate risk involves uncertainty as its effects are realised over long horizons. In addition, standard methods typically implemented in risk management, such as diversification or hedging through derivatives, are not disaster-proof. Natural disasters are highly unpredictable and add complexity to hedging activities. Yet, some financial players still focus on short-term horizons because of the inherent sophistication of predicting long-term effects.

Another important aspect is that asset managers can complement political action against climate change through corporate activism. One specific instance where activism has proved particularly helpful is in forcing disclosure of climate-related information. Environmental shareholder activism increases the voluntary disclosure of climate change risks, especially if initiated by institutional investors and even more so if initiated by long-term institutional investors. While disclosure efforts have triggered a visible shift in voluntary disclosure by several companies, the question is whether such information matters to asset managers and whether it in fact results in a subsequent reduction in emissions. Upon disclosure events, asset managers tend to divest of companies based on their levels of emissions, but not on changes in emissions. Mandatory disclosure policies may be necessary if greater disclosure is the planner's objective.

MITIGATING DISASTER RISKS TO THE FINANCIAL SYSTEM

The arrival of the Covid-19 provoked a collapse of equity valuations in the financial system. Recovery from the turmoil of March 2020 was possible not only due to timely fiscal and monetary interventions but also to regional-level mitigation by firms and governments, ranging from the quick implementation of vaccination programmes to other non-pharmaceutical interventions (NPIs) such as social distancing measures and testing. An example of the vital importance of public intervention was the implementation of Operation Warp Speed (OWS), which served to reduce the financial uncertainty in the development of a vaccine and changed how pharmaceutical companies assess the risk of conducting large-scale clinical trials on a new vaccine.

The experience of Covid-19 can be used to draw lessons on the importance of a portfolio of mitigation measures for increasing the resilience of the financial system to natural disaster shocks. An analogy that can be drawn is whether public–private partnerships can make investment in green infrastructures and technologies for carbon removal a priority. Costly adaptation – such as net-zero firm emissions targets by means of spending on decarbonisation technologies, coastal green infrastructure and protection of biodiversity – is needed to reduce aggregate risks and improve social welfare.

Another lesson is that the development of vaccines for Covid-19 is not equivalent to the control of greenhouse gas emissions through carbon taxes. The reason is that measures to mitigate the effects of climate change, such as seawalls to protect against sea level rise, do not have a direct impact on firms' earnings, in contrast to Covid-19 mitigation activities that protect workers. As many decarbonisation measures reduce aggregate risks to the financial system but do not affect firms' earnings, a tax on capital might be needed to fund efficient mitigation due to the presence of externalities. Sustainable finance mandates that restrict capital market investments to firms that meet mitigation spending thresholds may be a substitute for such a tax, but they must be significantly more stringent than is observed in practice to achieve an efficient outcome.

The role of central banks and banking supervisors in climate action[1]

Pablo Hernández de Cos[2]
Governor, Banco de España

Climate change has, in recent years, come to the fore of the concerns of the overall financial sector, including firms, supervisors and central banks. Let me offer some brief remarks on this topic, starting with the impact of climate-related risk on the financial sector and the role of regulators and supervisors, and followed by the connection between climate change and the conduct of monetary policy.

CLIMATE-RELATED RISK FOR THE FINANCIAL SECTOR AND THE ROLE OF REGULATORS AND SUPERVISORS

Across studies measuring the impact of the various industries and sectors on climate change, the financial sector is usually classified among the more environmentally friendly branches of activity. This is because greenhouse gas emissions stemming from the financial sector are very low the activities it engages in do not significantly affect the environment.

While this is true, the financial sector is actually highly exposed to risks associated with climate change by funding other sectors, including those that are exposed to extreme weather events or those that will be affected by the transition to a more sustainable economy.

Therefore, climate change poses two types of risks for the financial sector: physical risks and transition risks.

Physical risks are those that would materialise as permanent alterations of the climate, if we do not act to prevent global warming. Natural disasters would then become more frequent and their economic damage probably greater. In fact, there is evidence that such risks are already materialising to some extent. According to the Financial Stability Board,[3] global economic losses associated with catastrophes related to weather events have doubled since the 1990s, up to $1.6 trillion over the last ten years.

1 This is an edited version of the speech delivered at the IESE online conference "Resilience of the financial system to natural disasters" on 17 March 2021.
2 The views expressed here are those of the author and do not necessarily represent the views of the European Central Bank or the Eurosystem.
3 Financial Stability Board (2020).

And while it is true that financial markets and instruments covering these risks have been developed, these developments are unlikely to fully tackle the challenges of climate change due to (i) the sheer magnitude of climate risks; (ii) the sizeable exposures of the financial sector to this form of risk; and (iii) the presence of externalities.

The financial sector is exposed to these physical risks through several channels. Physical risks are of course relevant for the valuation of real estate assets, the main collateral of bank loans. Physical risks also matter when assessing the ability to pay of borrowers involved in sectors that could be particularly affected, such as agriculture or tourism. Capital destruction could also be very important. Furthermore, since not all geographies would be equally affected, the migration of activities and of the population in some areas will increase, generating an impact on the financial sector as well.

Precisely to prevent these risks increasing further, acting to prevent the materialisation of climate change is essential. However, such interventions, and the accompanying changes in consumer and investor sentiment in favour of a greener economy, may also create their own particular risks for the financial sector.

Indeed, the **transition** towards an environmentally sustainable economy implies a sweeping change in production technologies and a reallocation of activity across sectors and companies. Actually, such restructuring will mean that, in the short run, some sectors will increase their profits while others will incur losses, with obvious implications for the financial system and its stability. In this case, for estimating transition risks, the most relevant factors are the carbon footprint and the environmental impact of the sectors and companies to which financial firms are exposed.

In this context, and as part of our main responsibility to guarantee the stability of the financial system, we – regulatory and supervisory authorities – must ensure that the materialisation of climate risks does not endanger financial stability. Therefore, we must make sure that financial firms address these risks.

In particular, we should contribute to identifying climate risk drivers and their transmission channels, to the adequate measurement of the economic and financial impact of the different risks, and to the definition and development of the potential mitigation and risk-reduction measures.

If we succeed in incorporating these risks into the decisions of the financial sector, this will translate into a change in the relative prices of financial instruments. This, in turn, will help to internalise those consequences originating from both the transition and the physical risks that directly affect providers and users of funds. This will be a powerful and much-needed complement to the use of the fiscal and environmental instruments that are needed to fight climate change.

In practical terms, climate risk can probably be captured in the traditional financial risk categories (credit, market, liquidity or reputational risks). However, several crucial limitations and challenges come to light when trying to measure these risks. In particular, there are few databases that are sufficiently deep and harmonised to allow us to analyse and understand the potential effects of physical and transition risks. Data granularity is particularly important given the high heterogeneity of the potential impacts. And, while we are working hard to improve available information, we lack sufficient historical depth to be able to use the past as a guide to estimate future developments. In addition, there is no previous experience of structural changes of this magnitude, which also require a very long-term perspective and where the presence of non-linearities and irreversible tipping points are likely, conditioning the methodologies to be used. And there is limited research, and accompanying data, that explores how climate risks feed into the financial risks faced by banks. In this context, many supervisory and/or prudential authorities are opting to use stress tests and scenario analysis.

As a result, we should accept that efforts to translate climate-related risks into quantifiable financial risks are in their early stages. And we will have to step up our efforts to address these problems and limitations. It is also crucial that these efforts are coordinated at the global level, given the global dimension of the risks and the potential spillovers that can arise through interconnections between the real and financial sectors.

In this regard, in the case of banks, at the Basel Committee on Banking Supervision (BCBS) level we are planning to conduct a 'gap analysis' to identify areas in the current Basel framework where climate-related financial risks may not be adequately addressed or are not captured. This gap analysis will be comprehensive in nature, and will cover regulatory, supervisory and disclosure elements.

Building on the analysis, we plan to explore practical solutions to address any identified gaps. In addition to a set of principles or guidelines on effective supervisory practices for assessing climate-related financial risks, the Basel Committee will explore whether any policy measures under the regulatory framework should be taken, and how the Committee could support international efforts related to the development of globally consistently sustainability reporting requirements.

Importantly, any changes proposed by the Basel Committee to its regulatory framework would be in pursuit of its mandate to strengthen the regulation, supervision and practices of banks worldwide with the purpose of enhancing financial stability.

CLIMATE CHANGE AND THE CONDUCT OF MONETARY POLICY

Let me now turn briefly to the second topic: the implications of climate change for monetary policy, an issue that is also being analysed in the ongoing review of the ECB's monetary policy strategy.

The EU Treaty sets price stability as the single primary objective of the ECB. At the same time, the treaties also establish that, without prejudice to the primary goal of price stability, the ECB shall support the general economic policies of the Union, among which the fight against climate change has become a priority.

Indeed, it can be argued that given the long-reaching implications of climate change for so many economic and financial domains, in our pursuit of price stability, monetary policymakers cannot ignore the transition and physical risks that I mentioned above.

In particular, insofar as climate risks affect the macroeconomy, the inflation outlook or the transmission of our monetary policy, then such risks are bound to affect the conduct of monetary policy.

One fairly direct channel is the following. Policies aimed at promoting the transition towards a carbon-neutral economy – such as carbon taxes – are likely to affect the volatility of headline inflation, which includes energy prices. Most inflation-targeting central banks, including the ECB, target headline inflation because it is more representative of the citizens' consumer basket than other notions of inflation. The ECB's medium-term orientation of our price stability objective provides us with some leeway to see through transitory energy-driven increases in headline inflation. However, persistent upward pressure on, or substantial volatility in, headline inflation stemming from sustained climate policies could lead us to rethink how we formulate our policies in pursuit of price stability over the medium-term horizon.

More indirectly, but no less importantly, climate change and the remedial actions needed to tackle it could affect central banks' ability to achieve price stability through their impact on the so-called natural interest rate,[4] which is an important benchmark for inflation-targeting central banks when setting our interest rates. Natural interest rates in advanced economies, including the euro area, have declined in recent decades, reflecting structural shifts in the balance between aggregate saving and investment. The decline in natural rates has shrunk the space for interest rate policy owing to the existence of a lower bound on nominal interest rates, thus making it harder for central banks to achieve our inflation aims. Climate change will likely affect the natural interest rate, but it is not obvious in which direction. On the one hand, it could (further) depress natural rates

4 The natural interest rate is the level of real interest rates consistent with aggregate output being at its potential level and inflation stable at its target.

through negative effects on productivity, such as the impact of higher temperatures on labour supply and the destruction of capital stemming from natural disasters. However, the transition towards a more sustainable economy will require substantial investment in green technologies, which may push real rates up.

Clearly, more analysis will be needed before we have better answers for the implications of climate change on the economy and on monetary policy. And, in this regard, we have to step up our efforts, at both the Banco de España and the Eurosystem, to develop the tools and models needed for such an analysis.

In addition, climate change will affect the risks of the assets held on our balance sheets. Monetary policy implementation exposes us to such risks directly through holdings of assets and indirectly through collateral pledged by counterparties. In this regard, and very much related to my previous comments on the implications of climate change for the financial sector, central banks also have to step up their efforts to incorporate climate change into their risk management models and frameworks. And this, together with climate-related disclosure requirements, can decisively contribute to the correct pricing of climate-related risks by financial markets.

Moreover, central banks can – and probably should – use their non-monetary policy portfolios, within the natural remit of their mandates, with a view to contributing towards the goal of addressing climate change. Actually, the Banco de España has led by example in recent years in adopting these considerations. Since 2019, we have applied sustainability and responsibility investment principles to our non-monetary policy portfolios, which has effectively led to an increase in the share of green bonds in these portfolios. More recently, the Eurosystem has agreed on a common stance on this issue, aimed at contributing to the transition to a low-carbon economy and to EU climate goals by increasing the awareness and understanding of climate risks while promoting climate-related disclosure.

To conclude, we central bankers and financial regulatory and supervisory authorities, within our mandates of guaranteeing price and/or financial stability, can and should actively contribute to global action to fight climate change.

CHAPTER 1

Introduction

The global financial crisis of 2008–2009, and others before, were caused by the endogenous instability of the financial system. The Covid-19 crisis is an entirely different crisis, one that is caused by an external shock – a natural disaster. The fight against the global pandemic has led to lockdowns, interrupted economic activity around the world and tested financial stability. In large part thanks to the massive fiscal and monetary interventions to support households and businesses during the pandemic, we have escaped another global financial meltdown.

But the pandemic raises the question of how resilient the financial system is to natural disasters. At the same time, the Covid-19 crisis provides a large-scale natural experiment to address this question, and squarely puts natural disasters, whether they be pandemics or climate catastrophes, on the agenda of private institutions, bank regulators and central banks.[5] As with the coronavirus pandemic, climate change exposes us to tail climate catastrophes and systemic risks. It is also associated with global externalities that call for regulation, supportive public intervention and international coordination.

This report studies in what ways climate and natural disaster risk is different from other, more familiar forms of financial and economic risk and how banks, asset managers and central banks are beginning to grapple with these risks. Covid-19 has made us aware of the potentially devastating effect of natural disasters and provides a pointer to the effects that climate change may induce. There is a direct link between the two types of natural disaster since deforestation has increasingly put wild animals such as bats, which are carriers of deadly viruses, in close contact with people, thereby facilitating the transmission of these viruses to humans. It has also revealed the lack of preparation of our societies to confront a pandemic, despite multiple warnings from scientists and world leaders. Similar warnings have been made for a long time about climate change.

Covid-19 has, however, brought a piece of good news: the speedy development of vaccines. In less than a year, vaccines have been developed when the average development time in the past has been in the range of 10–15 years. This has been a triumph of science and has illustrated the power of planning and incentives in bringing forward vaccine development. Indeed, in Operation Warp Speed (OWS) the US government established a concerted public–private effort to incentivise drug companies to develop vaccines as quickly as possible.[6]

5 In the second report of the Banking Initiative, we study the potential impact of Covid-19 on the bank business model (Carletti et al., 2020).
6 See CRS (2021) for further operational details regarding the OWS contracts.

While waiting for the arrival of vaccines, the consequences of the pandemic for financial markets have nonetheless been severe as society has had to use costly mitigation strategies to limit the damage of Covid-19 by protecting workers from the pandemic through encouraging working from home and shutting down travel. The role of the public sector backstop has been crucial in avoiding a full-fledged financial crisis. A first important observation regarding the response to natural disasters is that, as Mario Draghi has stated,[7] only the balance sheet of the public sector can cope with the effects of a pandemic that brings several sectors of the economy to a halt and that deeply scars society and the economy. Pandemic risk is not 'hedgeable' with the usual financial instruments. Public support packages to the economy have reached staggering proportions, with President Biden's $1.9 trillion rescue package being a recent addition.

Given the good news on vaccine development, government intervention has largely proved to be effective in avoiding a wave of corporate bankruptcies following the coronavirus outbreak.[8] Central bank interventions have also been crucial in helping avoid a systemic crisis, starting with the containment measures provided in the United States in response to the bond market rout in March 2020. The financial stability remit of central banks has been moved to the forefront again. Contagious bank failures (a Lehman event) have not been a problem this time round, although we will have to wait and see the impact of the crisis on the solvency of many corporations once the public financial support is withdrawn.

The fight against climate change will also have to combine public intervention in the form of regulation, tax/subsidy schemes and the financial stability support of central banks with private sector mitigation strategies by investors, asset managers and companies to anticipate, hedge against and limit the effects of climate change. We can understand the Covid-19 pandemic as a wake-up call to act not only to prevent and protect against future virus-induced pandemics, but also to act now against climate change. Climate change risk is another risk that is not hedgeable with standard financial instruments. No-one can escape from it or play the role of insurer. Moreover, the private sector does not have the right incentives to protect itself against climate change-induced catastrophic risks materialising over a very long horizon. Here again, public–private partnerships, of the Operation Warp Speed type, may be called for. Importantly, public–private cooperation can be designed to complement financial markets and institutions and to reallocate resources to climate mitigation technologies.

Natural disasters such as climate change involve several externalities. The major one is CO_2 emissions, but there are others related to health issues, R&D spillovers and learning curve effects. Pigouvian taxation of greenhouse gas (GHG) emissions is a classical way of addressing the emissions externality. To prevent carbon leakage, this could also involve a carbon tax adjustment at the border if emissions are not sufficiently taxed by exporting

7 See the *Financial Times* of 25 March 2020.
8 Elenev et al. (2020).

countries. As conceptually straightforward as the policy response to CO_2 emissions is to economists, though, one cannot fail but note that almost all governments around the world have so far failed to deliver on the promise of effective carbon taxes. Carbon pricing is far from ubiquitous, with only 22% of emissions currently covered by some form of carbon price.[9] There are, of course, major political constraints and international coordination obstacles to the introduction of taxes, which is why other interventions in the form of regulations or standard setting must also be considered.[10]

An important alternative approach to controlling carbon emissions that has increasingly been taken by countries is to make quantity commitments, setting net zero emission targets mostly by 2050, by 2060 for China, and for a few ambitious countries even by 2040. Economic actors must have the right price (or shadow price) signals, but this can also be accomplished with quantity regulation.[11] The question, however, is how to implement such commitments – for example, net-zero commitments need a precise, non-manipulable definition. Quantity regulation has the advantage of fixing the total maximum amount of emissions and therefore potentially provides a better control of tail risk. This is the approach taken by the Emissions Trading System in the European Union, which is overcoming its early implementation problems. Whatever the approach to fighting climate change, what is crucial is that since it is a global problem, the solution has to be global. Otherwise, efforts in a certain sector of the economy or region of the world may be undone in another sector or region.

Sustainable finance mandates backed by large asset managers, sovereign wealth funds, pensions plans, along with central bank supervision and regulation have been proposed to incentivise the private sector to meet net-zero quantity commitments. These mandates are often implemented as passive screens whereby a fraction of wealth is restricted to being invested in companies that meet certain sustainability guidelines. To meet net-zero targets and in order to qualify to be held in investors' sustainable portfolios, firms have to spend enough on measures to mitigate the effects of climate change. Companies that qualify benefit from higher stock prices (i.e., a lower cost of capital) compared to those that do not qualify. Since most mitigation pathways to net-zero emissions require a portfolio of decarbonisation technologies, including negative emission technologies (NETs), the success of these mandates will depend on the financial commitment of shareholders to fund firms' spending on decarbonisation to offset the carbon emissions from their production.

9 See World Bank (2020). Furthermore, establishing the social cost of carbon is not easy due to the interaction of uncertainty derived from climate and economic modelling (Barnett et al., 2020a,b). See also Metcalf and Stock (2020) for an assessment of the effectiveness and macroeconomic impact of carbon taxes in the European Union.

10 More than 3,500 economists signed the Climate Leadership Council's statement in favour a carbon tax (see *The Wall Street Journal* of 17 January 2019 and the statement at https://clcouncil.org/economists-statement/).

11 See Vives (2011) and Cantillon and Slechten (2018) for models of how emission trading markets may aggregate information on pollution damage and help firms' abatement decisions.

Natural disasters are a major source of systemic risk, and therefore finance has to play a major role in the prevention and taming of these risks. The theme of this report is precisely testing how resilient the financial system is to natural disasters and what can be done to make it more resilient. Financial markets, institutions and regulators must complement the actions taken by the public and private sectors to mitigate natural disaster risk such as climate change. Central banks must maintain economic and financial stability and therefore need to react to this source of systemic risk, as argued in Chapter 2. Natural disaster and climate shocks pose a fundamental question for the lender of last resort (LOLR) as a policy response to dampen the financial and economic repercussions of such events. Private actors must deal with these risks from the investment side, and financial markets must provide accurate signals of costs and benefits of the public and private actions taken to tame these risks.

In Chapter 3 we describe how the financial industry has responded with an array of hedging instruments – ranging from insurance, reinsurance and catastrophe bonds to low-carbon index funds – that allow investors to try to hedge against natural disaster and climate risk. However, for the most part natural disaster and climate risks are systemic risks that investors are exposed to and that cannot be fully hedged. Sustainable finance mandates to incentivise firm spending on decarbonisation have also been embraced by the asset management community. The public sector, with its large balance sheet, may be called to the rescue, as we have witnessed during the Covid-19 crisis.

In Chapter 4 we calculate the size and qualification standards of sustainable finance mandates that are needed for the private sector to meet net-zero targets by 2050. We seek to clarify the required financial commitment of shareholders subscribing to sustainable finance mandates by combining projections of the damage from global warming to economic growth absent mitigation spending on decarbonisation technologies with projections of the cost of negative emissions technologies, such as carbon capture and storage.

In the rest of this chapter, we summarize the analysis and conclusions in this report. Section 1.1 reviews the physical and transition risks associated with climate change and whether the risk-management tools available are suitable for the task. Section 1.2 recapitulates the role of central banks as stabilisers of extreme events and in the transition to a green economy. Section 1.3 condenses asset managers' responses to natural disasters, while Section 1.4 deals with the role of mitigation strategies for disaster risk and sustainable finance mandates.

1.1 GREEN SWANS AND RISK MANAGEMENT

What are the risks associated with climate change? Are the usual risk-management tools appropriate?

Climate risk complexity: Physical and transition risks. Physical risks comprise the economic and financial losses driven by extreme events, as well as the effects of long-term changes in climate patterns (such as ocean acidification, sea level rising, changes in precipitation patterns, or wildfires, among others). The realisation of these physical risks alone could expose financial institutions to losses that are larger than their capital cushions. Only the drastic reduction of carbon emissions can limit the exposure to these risks.

Such a decrease, however, will expose the financial system to transition risk, which involves uncertain financial impacts resulting from rapid shifts from fossil fuels to renewable energy, the introduction of carbon pricing, potential reputational costs for fossil fuel energy producers and consumers, technological shocks to energy production (from breakthroughs in hydrogen, solar and wind power, battery technologies or carbon capture), as well as changes in market preferences and social norms.

The size of this transition risk may be quite large when seen in the context of the net-zero commitments made by government and companies around the world. Importantly, to be able to avoid a temperature rise greater than 1.5°C with a reasonably high probability, the world must eliminate roughly 50 $GtCO_2$/year of GHG emissions by 2050. This means that from now on, global yearly CO_2 emissions must be reduced by roughly 7% or 8% per year – a rate in fact achieved in 2020 as a result of the lockdown measures introduced around the world to contain the spread of the coronavirus. It is the combined realisation of physical and transition risks, and the highly unpredictable knock-on effects they will generate, that constitute a '*green swan*' event or series of events.

Climate risk complexity also involves societal and geopolitical risks. The likely effects on society and on geopolitical stability must be included to fully understand the implications of physical risks. Systemic social and economic changes might result in failed states and other breakdowns in countries in the most vulnerable areas because of rising temperatures. Extreme temperatures will give rise to geopolitical risks, the full ramifications of which are hard to foresee. Even in the case in which the physical effects of a warming planet could be traceable in terms of productivity losses or financial value, it is an oversimplification to merely model the ultimate effects on productivity and stock valuations. Keeping track of the physical costs of climate change on society is vital to assess mitigation policies, and to figure out the social changes needed for sustainability

Conventional risk-managements tools are inadequate to control climate change risks. The systemic nature of climate change implies a full reassessment of current risk-management approaches. First, traditional approaches based on a backward-looking risk assessment cannot capture the longer horizon of climate-related events. As the natural environment is changing, future states of the economy cannot be characterised as deviations from a steady state under a probability distribution that is estimated from past realisations of economic states. Second, conventional risk-management approaches that integrate a climate dimension into standard macroeconomic growth models do not fully capture the expected physical implications of global warming. Integrated assessment models (IAMs) are highly aggregated models that simplify the description of the economy, excluding any reference to transition risk, financial markets, financial crises or financial constraints. They focus on physical damages and seek to quantify the economic costs of these damages with the objective of assessing the social cost of carbon. They are useful to frame scenarios but, from the perspective of financial regulators seeking to manage climate change risks, IAMs are not a sufficient statistic when it comes to the quantification of risks similar to current financial risk metrics.

1.2 NATURAL DISASTERS, CLIMATE CHANGE AND CENTRAL BANKS

What is the role of central banking in the transition to a green economy? To what extent should central banks design a green response tied to the price stability mandate? How can we incorporate climate change into central bank mandates? How should prudential regulation take account of climate risk? Should the conduct of monetary be modified and, if so, how?

Central banks must include natural disaster risk in their prudential policy frameworks. Central bank mandates have been reshaped to focus more on financial stability than on controlling inflation and economic activity, as explained in the first report of the Banking Initiative.[12] While central banking had a narrow framing around monetary policy and price stability, the global financial crisis highlighted the importance of the role of central banks as lenders of last resort in a financial crisis, and their fundamental role in controlling systemic risk.

Maintaining financial stability requires *systemic risk management*, and both natural disasters and climate change are sources of systemic risk. Indeed, natural disasters can severely affect economic activity and quickly destabilise financial markets. As we saw in March 2020 with the Covid-19 crisis, they can simultaneously trigger a sharp stock market correction, resulting in a major loss of financial wealth, and a spike in demand for liquidity. From a financial stability perspective, therefore, central banks must include natural disaster risk to their prudential policy frameworks.

However, the policy response to stabilise the financial system should avoid an excessive reliance on central bank backstops. Indeed, the expectation of a bailout provokes moral hazard in lending and excessive risk taking, and therefore LOLR interventions should not become the default action to stem a financial crisis. When a crisis unexpectedly happens

12 Bolton et al. (2019).

as a result of an unforeseen event (say, a global pandemic), the LOLR is a necessary and expedient response to quell the crisis. But if the natural disaster and its financial repercussions can be anticipated, and if an appropriate risk management policy can be put in place to limit both the incidence and impact of the disaster, then there will be less of a need to rely on LOLR.

Today, the community of central bankers, financial regulators and supervisors accepts that climate change poses potentially systemic threats to financial stability, but the issue is being debated. On one side, we have the defenders of central bank independence and a narrow mission for the central bank, while on the other we have those concerned about the urgency of the climate crisis and the implications for financial stability. Even if central banks have powerful tools at their disposal that could be applied to reverse carbon emissions, by themselves they are not able to solve the climate crisis. Despite this, central banks must play their part along with other actors in the drive to decarbonise our economies. The ECB, for example, has a secondary remit to "support the general economic policies of the Union ...". However, Fed Chairman Powell has stated recently that climate change "is an important issue but not principally for the Fed".

We think that central banks must have a well-defined mission, of which the preservation of financial stability is a central part. This strikes the right balance between the danger of 'mission creep', where the central bank keeps adding tasks with accountability suffering, and an overly narrow mission definition (such as inflation targeting), which, as recent crises show, is not useful to stabilise the economy in the face of a deep financial crisis. This implies that climate change falls under the remit of the general mission of central banks to preserve financial stability, independently of secondary remits to accompany general policies of a country or region.

Measuring and reporting carbon emissions is the first step in any attempt to manage climate change risks tied to carbon emissions. Common limitations to the abatement of carbon emissions are the lack of data and inadequate methodologies to assess the underlying emissions of a firm's portfolio. As such, still only a few companies disclose their emissions, and even fewer financial institutions report their carbon footprints. Public forces, however, can accelerate the reporting of carbon emissions through supervision and regulation. Although corporations should be required to report their carbon footprint annually, as is already the case for listed companies in the United Kingdom and other jurisdictions, future projected emissions up to a three-year horizon should also be required, in line with their net-zero commitments. In a similar way, financial institutions should be required to report their carbon footprints on an annual and projected basis, as well as their commitments to decarbonise their portfolios and/or balance sheets. Reporting the carbon footprint at the firm level would facilitate the monitoring of the advances of companies in reducing GHG emissions, and the progress of financial institutions in decarbonising their portfolios.

Forward-looking scenarios and climate stress tests must be designed to facilitate the risk management of climate-related risks. The complexity of the risks posed by climate change imply that central banks need to make holistic, interdisciplinary risk assessments. The Network of Central Banks and Supervisors for Greening the Financial System (NGFS) has concluded that a good basis for such an approach is to build forward-looking scenarios. It is not enough to measure risk by profits and losses within a one- or two-year horizon at an individual financial institution. It must be measured directly through exposures on carbon (physical risk) and by testing the financial repercussions of reducing these exposures for the whole financial system and the whole economy (transition risk). IAMs have proved useful to structure forward-looking scenarios and assess the social price for carbon, but by and large they do not address the complexity of the risks involved and the radical uncertainty we face when tipping points are crossed. Furthermore, forward-looking scenarios should allow for the presence of boundedly rational agents, for the evolution of societal perception of climate change, and for imperfect and incomplete markets. It must be recognised, however, that scenario analyses do have limitations and are tentative in nature.

Several central banks have pushed for the definition of forward-looking scenarios and climate stress tests. The Biennial Exploratory Scenario (BES) by the Bank of England, which plans to test major UK banks and insurers to estimate the size of their climate risk and carbon exposures under three scenarios over a 30-year time horizon, is a good example. The logic behind the three scenarios is to identify not only the size of climate risk exposures in the banking and insurance sectors, but also the extent to which an orderly transition path, with early action, is feasible. The benefits of the BES exercise are the provision of granular information about climate risk exposures at the firm and the institutional level and the setting of a consistent methodology for assessing transition paths and risk assessments at the firm level. Another example is provided by the De Nederlandsche Bank (DNB). Similarly, to improve the disclosure of environmental risks, the ECB plans to implement climate stress tests for banks starting in 2022.

The scope for climate prudential regulation. Regulatory intervention to induce banks to limit credit to companies with high emissions would certainly give central bank climate risk management more teeth. For example, the methodology of risk-weighting of the assets-to-capital ratio could be modified by adding a carbon weighting of assets component. Adding a carbon emissions weight to the weighting of bank assets for capital regulatory purposes could be an effective way of tilting bank incentives away from brown assets towards green assets. Another matter is whether capital requirements can be used in a more pro-active way to favour green investments and loans. Here, who will define what 'green' is and what it is not will be very important, and a careful assessment of the loans' risk level is needed to avoid subsidising riskier investments. Indeed, central banks are not the right institution to conduct targeted lending. If very risky innovation to combat climate change is to be promoted, the public sector should provide funding via public–private partnerships. Similarly, once the periodic conduct of climate stress tests is in place, central banks could tie bank dividend payments to passing the climate stress test. If it is found that bank is on a carbon footprint pathway that is incompatible with achieving the net-zero target risk to the banking system, that would justify a suspension of dividend payments.

A more difficult and controversial question is how climate change risk considerations should influence the conduct of monetary policy and the management of central bank reserves. To start with, both the long-term and the short-term effects of climate change must be taken into account. The long-term effects may influence both the estimates of the natural rate and the potential growth of the economy, while the short-term effects may induce higher volatility due to an increased incidence of severe weather disturbances in the economy or due to the effects of regulatory and fiscal measures provoking relative price changes. Price stability may be important here so that economic actors do not confuse movements in the price level with relative price adjustments. The long-term effects on the natural rate may be ambiguous since, while the increased investment needed to combat climate change may call for a higher rate, the destruction of capital and stranded assets may call for a lower one.

It is worth noting also that by applying the neutrality investment principle, central banks are by default tilted towards assets from companies associated with high carbon emissions, whether directly or indirectly. The reason is that market prices do not fully reflect environmental damages, and therefore the market is not neutral. To enhance their credibility, central banks also have to report their carbon footprint and make clear statements towards their decarbonisation to discipline the financial institutions under supervision. As such, more transparency regarding the carbon footprints of the eligible collateral and reserve asset management would help to align central bank policies with the broader net-zero commitments of their countries.

In summary, central banks cannot content themselves with developing forward-looking scenarios and implementing climate stress tests, since such a passive stance could expose them to not being able to deliver on their financial stability mandate. Central banks can play a more proactive role in promoting mitigation policies and coordinating their own climate risk management policies together and with other actors in government, the private sector and civil society.

1.3 ASSET MANAGERS' RESPONSE TO NATURAL DISASTERS

What is the role of diversification, insurance and hedging strategies in managing climate risk? How do the systemic nature of natural disasters and the potential persistence of shocks affect such strategies? What is the relative importance of divestment and activism? Is mandatory disclosure of climate risks necessary? Are asset managers' actions complements to or substitutes for mitigation efforts by the public and the private sectors?

Recent shocks such as the global financial crisis, the Covid-19 outbreak or concern about the climate crisis have shifted the traditional asset management paradigm. A question that must be addressed is the extent to which the financial sector can respond to the arrival of such disaster events. Large investors are conscious of the realisation of climate-related risks.[13] Indeed, one of the main challenges is that standard risk management methods, such as diversification or hedging through derivative instruments, are not disaster-proof as they either do not hedge risks on a large scale or do not capture all the relevant states for climate-related risks.

However, there is a role for markets to issue assets with more complete state contingencies, especially with respect to long-term risks. The evidence shows that stock prices reflect both long-term and short-term effects of transition risk. However, while we observe price patterns that are consistent with risk-based explanations, the main challenge is that traditional models of asset pricing are not suitable for testing whether climate risk is fairly priced, as they impose unrealistic assumptions on a deeply nonlinear problem with a non-stationary data-generating process.

The asset management sector plays an important intermediary role in global financial markets. At the same time, given their expertise, asset managers are well positioned to anticipate the occurrence of and consequences of natural disasters. The growth in environmental, social and governance (ESG) investments in recent years has been impressive. As of 2020, more than $40 trillion worth of assets managed globally have had some form of ESG consideration, with a vast majority being actively managed. The amount has doubled over the last four years and more than tripled over the last eight years. Behind this growth are an increase in client investor demand from both pension funds and individual investors, demographic factors and, quite likely in 2020, a push from the Covid-induced crisis. The investment horizon is a significant explanatory variable for investors' holdings of ESG stocks.[14]

The geographic distribution of sustainable investment is not even. Europe dominates the investment landscape, with over 80% of all sustainable assets under management, followed by the United States and Asia. Given the prominent role of asset management in the United States compared to Europe, the dominance of the latter is surprising. One reason is that sensitivity to climate-related risks is generally greater among asset managers in Asia and Europe because of the saliency of climate issues in those regions. From a competition point of view, this also means that asset managers in those regions are likely to be more constrained in their behaviour than those in the United States and that their ability to outperform global peers may be limited. 'Greenwashing' – the

13 See Krueger et al. (2020).
14 See Starks et al. (2017).

pretence put up by a fund or a company as a marketing ploy of being green, sustainable, or environmentally friendly – is a major issue for regulators. The EU is discussing and introducing new disclosure rules to define sustainable products with the aim to establish a taxonomy of sustainable activities.

Identification of downside risks and risk management of natural disasters is difficult. The systemic nature of natural disasters and climate change shocks makes them difficult to hedge because of the limited ability of financial players to share risks. Climate risk may provoke short-term changes or involve effects that are realised with a longer horizon. This uncertainty enters risk management in two ways. First, tail shocks are rare events, which leads to significant estimation error of any stationary system. Second, climate risk involves uncertainty resulting from a potential non-stationarity of the underlying wealth-generating process. The result is that natural disasters are highly unpredictable, and this adds more complexity to hedging activities.[15] A consequence is that, *although natural disasters materialise with different horizons, asset managers focus on short-term risks.* Asset managers should adopt a dual approach balancing both short and long horizons to respond to climate risks. Yet, what seems common is asset managers' focus on short-term risks because of the inherent difficulty in predicting long-term effects.

The systemic nature of natural disasters complicates portfolio diversification and hedging strategies. Private insurance may also be problematic or even unfeasible.[16] If risks are fully specified and priced, derivative contracts may come to the rescue.[17] In the context of natural disasters and climate risks, this could be in the form of catastrophic bonds or weather derivatives. However, risk-sharing by private institutions may not be feasible when all assets are systemically exposed to climate risk. If this were the case, the public sector may be instrumental in insuring such risks. In a general framework, the system could involve an insurer of last resort that would be able and willing to bear the financial cost. The advantage of using the public sector as an ultimate underwriter of risk is its ultimate funding ability guaranteed by its backing by taxpayers' money.

15 Tail events may have scarring effects on beliefs and consequently on economic activity. Kozlowski et al. (2020) claim that the long-term effects of the Covid-19 on the US economy might outweigh the short-term economic losses due to a persistent shift in the perceived probability of future extreme shocks. Tail events are unlikely phenomena for which data is scarce. However, when they realise, investors update their beliefs. The lack of reliable past evidence converts tail events into very informative signals leading belief revisions to become persistent and, consequently, potentially hampering economic activity. This scarring effect is expected to be stronger as less frequently similar data is observed, which suggests that belief changes may persist after the tail event is gone.

16 For example, recent large losses related to fires in California, combined with regulatory distortions, cast doubt on the continued ability of insurance companies to absorb fire-related losses. Somewhat surprisingly, Issler et al. (2020) using comprehensive data of wildfires in California from 2000 to 2018, find that the level of default and foreclosure decreases in the size of the wildfire due to coordination externalities afforded by large fires. This results from the coordination externalities afforded by large fires, whereby county requirements to rebuild to current building codes and casualty insurance-covered losses work together to assure that the rebuilt homes will be modernised and thus more valuable than the pre-fire stock of homes.

17 Given that some shocks do not have the same damaging consequences for every market participant at the same time, co-insurance may help.

Asset managers can complement public action against climate change through corporate activism (i.e., sustainable finance mandates). A mitigation activity aimed at augmenting resilience and reducing the stress on the entire system facing tail risks is necessary. Political actions are powerful but fragile, because coordinating mitigating actions is relatively costly. One of the most prominent activities asset managers can engage in is corporate activism to reduce GHG production. Investors' green preferences are reflected more and more in the boards of companies and by asset managers. In particular, universal owners, such as large asset managers and pension funds, may exert an important influence, inducing companies to internalise environmental damage given their concern for the economy at large.[18] One area where activism has proved effective is in forcing the disclosure of climate-related information. To price the underlying risks of climate change better, institutional investors (particularly long-term ones) demand from companies a direct disclosure of their carbon emissions. In the absence of high-quality data, this effort becomes especially relevant for assessing the costs and benefits of firms' transition to a green equilibrium. It must be pointed out, however, that asset managers are not a substitute for public intervention. Indeed, it is possible that the bulk of asset managers perceive ESG as one more factor to be considered. In addition, public actors have also enhanced their efforts to encourage disclosure of climate-related information. The policy involvement has been shown with two initiatives: the Paris Agreement and the Taskforce on Climate-Related Financial Disclosures (TCFD), which stipulates firms' commitments to disclose their carbon emissions and other climate-relevant information.

Mandatory disclosures might be required if more disclosure leads to divestment and increases in the cost of capital. The disclosure efforts have triggered a shift in voluntary disclosure, but the question is how such information matters to asset managers. There is evidence showing that, upon disclosure procedures, asset managers tend to divest of companies based on their levels of emissions, but not emission changes. Furthermore, there is evidence that such disclosure-driven divestment will influence voluntary disclosure policy. Indeed, to the extent that divestment increases the cost of equity, firms may be less likely to disclose their information voluntarily. As a result, mandatory disclosure policies (such as in the United Kingdom) may be necessary if such disclosure is desired.

Direct trading by asset managers may trigger change in corporate behaviour. 'Voting with their feet' by institutional investors can trigger corporate change, including the promotion of socially friendly policies. In the context of climate change, this would translate into divesting assets with a high carbon footprint. The mechanism to put pressure on the corporate sector could also involve some price effects, such as an increase in firms' cost of capital. Given that the cost of capital is one of the main determinants of

18 Azar et al. (2020) study whether asset managers can push to reduce corporate carbon emissions by attracting or retaining clients that are sensitive towards environmental issues. Using data from the 'Big Three' (BlackRock, Vanguard, and State Street Global Advisors), they find that firms with higher CO2 emissions are more likely to be the target of Big Three engagements, which suggests that firms under the influence of these asset managers may be more likely to be concerned with reducing corporate carbon emissions.

firms' investments and profitability, one can expect firms to internalise such divestment forces in their corporate policies (this has been documented with 'sin stocks' from the tobacco, alcohol, and gaming industries). However, evidence suggests that asset managers do not divest in a meaningful way of companies that are riskier from a carbon emissions perspective. Asset managers, on average, divest stocks based on their emission intensity, but intensity is not the best measure to capture the transition risk of moving towards low-carbon equilibrium, since lowering emission intensity does not necessarily imply lowering emission levels.

Asset managers and banks can facilitate the management of climate risk and promote green financing through their role as financing intermediaries. On the *asset supply side*, asset managers can purchase financial instruments whose proceeds are meant to support green initiatives. The supply of 'green' bonds, for example, has grown rapidly in recent years. Private equity firms can also engage directly in the development and financing of socially friendly technologies, such as financing solar energy. The intermediation industry, as asset originator, also has the capacity to issue a wide range of carbon-free contingent financial products oriented towards climate sustainability with the intention to hedge private investors against the underlying risks of natural disasters.[19] In addition, financial institutions can lessen the risk exposure of market participants by providing information services such as screening or monitoring. On the *asset demand side*, different types of managers accommodate different spaces on the financing spectrum. In the context of green bonds (bonds designed purposely to support certain climate-related or environmental projects),[20] bond funds and hybrid ESG funds are the most natural counterparties. Also, insurance companies, especially from Europe and Japan, are active buyers. When it comes to financing broadly defined ESG initiatives, endowments and pension companies stand out.

1.4 MITIGATING DISASTER RISKS TO THE FINANCIAL SYSTEM

What policy lessons can we draw from the Covid-19 outbreak? What is the importance of regional-level mitigation efforts to offset tail events such as natural disasters? What is the impact of mitigation strategies in stabilising the stock market? How should mitigation strategies be designed to achieve an efficient outcome?

The breakout of Covid-19 caused at first a collapse of equity valuations and liquidity stress in debt markets. A quick rebound was possible not only due to the timely fiscal and monetary interventions to compensate for the sudden stop in aggregate demand as consumers took shelter from the coronavirus, but also as a result of the early prospect of successful vaccines and mitigation strategies by firms and governments. Despite the initial slow response to Covid-19 in both Europe and the United States, which coincided

19 Engle et al. (2020) provide a methodology to for constructing equity portfolios that hedge against innovations in climate change news.
20 Green bonds still need a precise, widely accepted definition.

with the Covid-19 stock market crash, many jurisdictions implemented mitigation measures to varying degrees as vaccination programmes were being developed. These non-pharmaceutical interventions (NPIs) included testing, social distancing measures, and health checks.

The importance of government intervention in the resolution of natural disaster events such as Covid-19 was demonstrated with the development of vaccines. Government funding such as through Operation Warp Speed (OWS), announced on 30 March 2020, fundamentally changed the process. Beyond a large allocation of funds for vaccine research to developers, a crucial element was that the Department of Health and Human Services (HHS) built the needed infrastructure and guaranteed the manufacturing of any successful vaccines; it also purchased vaccine allotments prior to knowing whether the vaccines would be successful. With this public intervention, private firms obtained the certainty that a minimum quantity of products would be purchased in the future, which reduced private uncertainty over sales that might have disincentivised the development of a rapid solution at the same time that the public guaranteed the provision of a vaccine at reasonable prices. This changed how pharmaceutical companies assess the risk of conducting large-scale clinical trials on a new vaccine.

Given the apparent success of OWS, an analogy that can be drawn is whether public–private partnerships (PPPs) can make the investment in green infrastructures and technologies for carbon removal a priority. Climate-related natural events represent irreversible risks that will eventually materialise. As such, they require long-term commitments that foster funding of risky R&D for green technologies and the investment in infrastructures that contribute to the climate change mitigation process. For example, carbon removal technologies that run combustion in reverse could facilitate the removal of tonnes of CO_2 from the atmosphere at lower costs. To align public and private incentives when uncertainty is very large and private finance sources are not available, the PPP must be based on a commitment that the public entity will finance the development and adoption of the technologies required for carbon abatement contingent on the success of the investment project. Under the monitoring from the public side, this funding line could cover the initial costs derived from R&D and, contingent on the results and advances made, the rolled-over option to continue the implementation of the project.

Vaccine development helped stabilise stock prices. Not only is Covid-19 contagious but, due to environmental factors and/or mutations, community transmission rates are highly unpredictable. It follows that these transmission shocks are at least a regional risk factor. Evidence over 2020 suggests that there are also commonalities in the behaviour of Covid-19 across regions, such as in mutations. Therefore, there is also a potentially important systemic risk factor that will affect all firms' discount rates. When considering what drives discount rates for firms, business cycle factors come to mind and with Covid-19, the *uncertain transmission rate* is a new systemic risk factor that ought to be priced in the cross-section of stock returns. The highly contagious and unpredictable nature of Covid-19 also means that vaccines are crucial in mitigating the economic damage. This is so since the prospect of a vaccine limits the persistence of the Covid-19 shock and hence its negative impact on long-term earnings and stock prices. Collectively, vaccine development around the world has helped stabilise global stock prices. The quick rebound in equity valuations in the second half of 2020 is tied to the expectations of security analysts of a fast-arriving vaccine that limits prolonged earnings damage. Forecasts in mid-May 2020 implied an earnings crash and lower earnings growth until a vaccine arrived in one and a half years. However, mid-August 2020 forecasts implied a vaccine arrival in a little over seven months.

However, the prospect of vaccine arrivals is not enough to stabilise stock markets. A calibration based on the unpredictability of Covid-19 suggests that stock markets would still have been 15% lower absent firms' NPIs to protect their workers. For example, leading companies such as Microsoft were the first to disperse their workforce even before government actions. Indeed, US news suggests that it was these early corporate NPIs that triggered local governments to move on those actions as well, thereby also addressing potential coordination problems (externalities) associated with NPIs. When firms took precautions to mitigate Covid-19 risks early, companies may have faced initial losses since the actions were costly, but in the long run, those companies performed better than those that did not mitigate. Sacrificing the economy to save live entails a trade-off only in the short term.

What lessons for climate change risk can be drawn from the Covid-19 experience? The experience of Covid-19 can be used to draw lessons on the importance of a portfolio of mitigation measures for increasing the resilience of the financial system to natural disaster shocks. In the context of global warming, this means firms spending on a portfolio of decarbonisation measures such as NETs like carbon capture and storage, for example. An important observation is that externalities to mitigate climate risks are much larger than those involved in Covid-19 since the former, in contrast to the latter, typically do not impact firm earnings. Hence, government subsidies to further develop carbon capture technology, similar to those provided for vaccine development, might represent one of the best investments currently available even if, in the end, no breakthrough is guaranteed.

In lieu of a difficult-to-implement carbon tax, a tax on capital to subsidise decarbonisation may be an effective way of restoring efficiency. Decarbonisation measures do not directly impact firm earnings, in contrast to Covid-19 mitigation measures that protect workers. Their main benefit is in reducing aggregate risks to the financial system that firms take as given and therefore do not internalise. Hence, due to these externalities, a tax on capital is needed to fund efficient mitigation.

Three main observations can be made from a calibrated climate disaster model. First, absent any mitigation, business-as-usual projections of the damage from global warming imply that a climate disaster, similar in size to hurricanes that make landfall, is expected once every few months. Second, realistic risk preference profiles of households generate a substantial willingness-to-pay for mitigation and hence a sizeable optimal tax on capital. Third, even though mitigation comes directly at the expense of cash flows and investment, the hedging benefits of mitigation against disaster risks can significantly offset this negative direct effect to stock prices because it drives down the aggregate risk premium.

As a baseline scenario, we suppose that the portfolio of decarbonisation technology costs over the next 30 years reaches $144 per metric tonne. This would mean firms need to spend $3.6 trillion annually on decarbonisation, or 0.6% of the $600 trillion of global capital stock. Assuming that this spending would substantially mitigate the damage to economic growth, it is found that optimal mitigation spending is around 1.79% of the capital stock annually and social welfare is improved by around 60% compared to a competitive economy with no mitigation. In other words, net-zero emissions targets get us about half way to first-best outcomes.

An optimally designed sustainability mandate can in theory substitute for a capital tax, but existing mandates must be large enough and stringent enough to be efficient. Sustainability targets focus on companies that spend enough on decarbonisation technologies to meet net-zero emissions. With a restriction that a firm pays around 35% of its revenues as dividends (roughly the payout ratio for mature consumers or industrial companies), achieving the net-zero target aggregate spending of 0.6% of capital stock per annum requires that 38% of wealth be allocated to mandates and a qualification criterion requiring a firm to spend 1.6% of its capital stock each year on mitigation. The compensating cost-of-capital advantage for a sustainable firm over an unsustainable one is 0.90% per annum.

In summary, natural disasters associated with global warming, like rising sea levels, pose systemic risks in the future. Chapter 4 highlights the importance of mitigation in protecting the financial system from natural disasters. Costly adaptation, such as net-zero firm emissions targets via spending on decarbonisation technologies, coastal green infrastructure and protection of biodiversity, are needed to reduce aggregate risks and improve social welfare. Due to the presence of externalities, a tax on capital to fund mitigation is needed to restore efficiency in a competitive market. Sustainable finance mandates that restrict capital market investments to firms that meet mitigation spending thresholds can be a substitute for such a tax, but they have to be significantly more stringent than what is observed in practice to achieve an efficient outcome. This chapter puts a dollar value on the financial commitment needed from investors in sustainable finance mandates to incentivise industrial firms to meet net-zero emissions targets.

CHAPTER 2

Natural disasters, climate change and central banks

2.1 INTRODUCTION

Anyone brought up with the monetary economics of the 1990s would find the title of this chapter strange. The keywords associated with central banks at the time were, in no particular order, central bank independence, inflation targeting, and the Taylor rule for setting interest rates. Central bank mandates were quite narrow, and to achieve a credible commitment to maintain low inflation, the ideal independent central banker was seen to be someone who was slightly conservative, that is, someone who was more inflation-averse than average.[21] In retrospect, this narrow framing of central banking around monetary policy and price stability was somewhat atypical in the broader historical context of central banking. Central banks have been created with the initial goal of providing greater stability to the banking system, by intervening as a lender of last resort in a crisis. Controlling inflation was far from the concerns of the founders of the first central banks, whether it was the Riksbank, the Bank of England, or the Federal Reserve System. It was only much later, when a combination of prudential regulations, deposit insurance, and LOLR protections introduced an era of stable banking after the Great Depression, that attention shifted to the new macroeconomic challenges of controlling inflation and unemployment.

But the global financial crisis has brought back home the importance of the role of central banks as lenders of last resort in a financial crisis, and their fundamental role in controlling systemic risk. Following the financial crisis, the mandates of most central banks have been dramatically expanded. Whether in the European Union (where the ECB has been granted a major new supervisory function under the European Banking Union), in the United Kingdom (where the Bank of England has been granted a new mandate of maintaining financial stability and macroprudential regulation) or in the

21 See Rogoff (1985). After his speech at Jackson Hole in 1994 arguing that lower unemployment was an important objective for the Federal Reserve, Alan Blinder was deemed unfit to be a central banker by some prominent commentators in the financial press: "Put simply, Blinder is 'soft' on inflation… and lacks the moral or intellectual qualities needed to lead the Fed" wrote Robert J. Samuelson in *Newsweek* (see Neil Irwin, "The Most Important Thing Biden Can Learn From the Trump Economy", *New York Times*, 11 January 2021).

United States (where the Federal Reserve has expanded its supervision of systemically important financial institutions and introduced new macroprudential policies), central bank mandates have been reshaped to focus more on financial stability than on controlling inflation and economic activity.[22]

It is in the context of this redefined role of central banks that the title of this chapter, "*Natural disasters, climate change and central banks*", can be understood. The key observation is that maintaining financial stability requires *systemic risk management*, and both natural disasters and climate change are sources of systemic risk. If anyone ever doubted that natural disasters could be a source of systemic risk, we have just seen in real time how a global pandemic can disrupt the economy and cause a freezing of financial markets. At first it was thought that China had been able to confine the spread of the virus, but by March 2020 it became clear that Covid-19 was spreading rapidly in Europe and North America. Drastic mitigation measures would have to be introduced – full lockdowns for a prolonged period – to contain the virus and avoid a public health catastrophe. A financial market freeze ensued when governments announced the first containment measures and when analysts first understood the dramatic effects containment would have on economic activity. No-one had foreseen that a pandemic could so quickly precipitate a financial crisis. To avert a repeat of a full-blown financial crisis as in 2007, central banks had to respond quickly and forcefully. Their successful response contains two important lessons for how natural disasters can affect financial stability and the challenges such disasters pose for central banks.

The pandemic has taken on such extraordinary proportions, and so many dramatic events have occurred in 2020, that the financial meltdown of March 2020 has barely registered in our minds. Some commentators have argued that the reason why we were able to escape a generalised banking crisis in March is that banks were much better capitalised than in 2007. Banks did not fold because they had a sufficiently large loss-absorption cushion to be able to withstand the losses from the pandemic and the lockdowns. Certainly, the pandemic reinforced the importance of maintaining a well-capitalised banking system. Yet, the stronger bank balance sheets were not enough. Central banks still had to intervene massively as lenders of last resort to stabilise financial markets. In the United States, investors' flight to cash caused a run on money market funds and a freezing of the most liquid segment of financial markets, the Treasury bond market. In the euro area, flight to quality in euro government bond markets resulted in a sharp increase in spreads between Italian and German government bonds, raising the spectre of another euro crisis. Although they were initially reluctant to intervene, the Fed and the ECB quickly realised that they had no choice but to open the cash spigot. Thus, for the Covid central bank response, the more important legacy of the global financial crisis was not so much the better capitalised banking systems as the LOLR toolkit that had been put in place during the crisis and that could be quickly and seamlessly reactivated.

22 See Bolton et al. (2019).

The two lessons from this experience are, first, that natural disasters can severely affect economic activity and quickly destabilise financial markets. They can simultaneously trigger a sharp stock market correction, resulting in a major loss of financial wealth, and a spike in demand for liquidity. From a financial stability perspective, therefore, central banks must include natural disaster risk in their prudential policy frameworks. Second, the policy response to stabilise the financial system should avoid an excessive reliance on central bank backstops. LOLR interventions should not become the default intervention to stem a financial crisis. The reason, of course, is that the expectation of a bailout incites moral hazard in lending and risk taking. When a crisis unexpectedly materialises as a result of an unforeseen event (such as a global pandemic), LOLR may be a necessary and expedient response to quell the crisis. But, if the natural disaster and its financial repercussions can be anticipated, and if a suitable risk management policy can be put in place to limit both the incidence and impact of the natural disaster, then there will be less of a need to rely on LOLR.

Interestingly, there has been little political opposition so far to central banks' LOLR interventions in March 2020. This is in sharp contrast to the political commotion caused by the 'bailouts' of too-big-to-fail financial institutions during the global financial crisis.[23] There are at least two reasons for the different reactions. First, unlike the years preceding the financial crisis, there was no build-up of excessive risk by financial institutions before the outbreak of the pandemic. It is also less obvious that an LOLR intervention to stabilise the financial system during a pandemic will create a bad precedent that will encourage moral hazard in lending. Second, the LOLR intervention by the Fed took place in an election year, when concerns about supporting economic activity and limiting unemployment trumped strict adherence to traditional Republican principles against bailouts. Still, there are misgivings about the scale of central bank interventions in 2020, the unintended effects in terms of fuelling asset price bubbles, and the endogenous liquidity risks that remain unaddressed. Central banks were thrust into an LOLR response by necessity, not by design. Had they been able to plan for a suitable response to a financial meltdown triggered by a pandemic, they would surely have preferred to rely less on LOLR interventions. This is another reason why the prospect of natural disasters must be part of central banks' systemic risk management mandates – so that they can better prepare for such events and plan for more appropriate responses.

Yet, natural disaster and climate shocks pose the more fundamental question of the appropriate role of LOLR as a policy response to dampen the financial and economic repercussions from such a shock. As Chapter 3 describes, the financial industry has developed a whole array of hedging instruments – ranging from insurance, reinsurance and catastrophe bonds to low-carbon indexes – that allow investors to hedge against natural disaster and climate risk. But, for the most part, natural disaster and climate risks are systemic risks that investors are exposed to and cannot fully hedge against on

23 See Bolton et al. (2019).

their own. Some form of public sector backstop may therefore be necessary to absorb these shocks, as we have seen with the financial support given by governments to temporarily laid-off workers and shut-down businesses during the Covid crisis. Similarly, mitigation as a form of self-insurance may be required to limit these systemic risks, as we argue in Chapter 4.

Before the global financial crisis, carbon emissions were mostly seen by economists as an *externality* that needed to be priced. The focus of economic analysis was on Pigouvian carbon taxes and carbon emissions trading systems (ETS). In an ideal economic and political system, the carbon tax would be set at such a level that the marginal economic benefits from carbon emissions (i.e., the benefits from energy consumption) would be equal to the marginal expected costs to the planet (i.e., the expected damages from climate change). To be able to determine the social costs of carbon emissions, economists developed IAMs of increasing complexity, building on the foundational work of William Nordhaus.[24] A typical IAM would add energy inputs to a standard model of economic growth, and carbon emissions from energy consumption that would map into expected future changing temperatures, which in turn would cause physical damages modelled generally as losses in productivity. Thus, to achieve optimal long-term growth, carbon emissions would have to be taxed so that the marginal benefit from higher production today would be equal to the expected future loss in productivity caused by a warming planet.

A key conceptual challenge in determining the social cost of carbon (SCC) was to define the social discount rate at which future damages should be discounted to be able to compare the present expected cost with the benefit of emissions. A lively debate emerged around the social discount rate. No wonder, since a lower rate would result in higher estimated damages and mechanically imply a higher carbon tax. In a Ramsey growth model (the basis for most IAMs), the social discount rate is equal to the rate of time preference of the representative agent plus the coefficient of intertemporal substitution times the rate of growth in consumption (GDP).[25] The Stern Report used a rate of time preference equal to 0.1, a coefficient of intertemporal substitution equal to 1, and a rate of growth of GDP equal to 1.3, obtaining a social discount rate equal to 1.4.[26] In contrast, William Nordhaus recommended using a rate of time preference equal to 1, a coefficient of intertemporal substitution equal to 2, and a rate of growth of GDP equal to 2, obtaining a much higher social discount rate equal of 5, and therefore much lower estimates for the damages produced by carbon emissions and global warming.[27] As lively

24 See Nordhaus (1975, 1977).
25 See Ramsey (1928).
26 See Stern (2006).
27 See Nordhaus (2008).

as this debate was, it remained largely within the confines of academia, with almost no bearing on public policy. Even the most optimistic estimates of limited climate change-induced damages required setting a carbon tax far higher than what almost any country was prepared to do.

It is remarkable that no role for financial markets is allowed in these economic analyses of optimal carbon taxes. There is no mention of how investors assess the implications of climate change, of the systemic financial risks created by climate change, or of the inevitable role financial markets must play in financing and guiding the energy transition. William Nordhaus does argue that the social discount rate used to determine the present cost of future climate damages must be in line with the discount rate used by investors, and in so doing he implicitly accepts that financial markets are rationally forecasting climate change and its effects. But what if investors are in denial and simply oblivious to the perils of climate change, as Al Gore has maintained?[28]

The global financial crisis brought home starkly the risks of overlooking emerging bubbles fuelled by runaway debt markets. Couldn't obliviousness to climate change become an even more toxic source of systemic risk and set up the next financial crisis? This is essentially what Robert Litterman has argued:

> *Not pricing risk appropriately leads to disasters. Start by thinking about what would be the appropriate price for carbon emissions today. What should the price reflect? The price should reflect the risk created by carbon emissions, clearly.... Yet the situation we have today with respect to carbon emissions, is that not only are emissions currently not reflecting a premium, they are not even reflecting the expected discounted damages. How serious is it when a systematic risk is not priced appropriately? Recall that what caused the financial crisis was also a systematic risk that wasn't being priced. Not pricing systematic risk leads to too much risk being taken, and such a situation will eventually lead to a high probability of a global catastrophe.*[29]

Thus, the global financial crisis has changed the framing of the economics of climate change. Carbon emissions are not just an externality that needs to be priced, but also a financial risk that needs to be managed. If only due to the systemic financial risk that it poses, climate change risk must therefore be part of the financial stability mandate of central banks.

28 See Gore (2006).
29 See Litterman (2010).

The remainder of this chapter will proceed as follows. Section 2.2 reviews the debates around central bank mandates around climate change and the process by which central banks have gradually recognised their responsibility for dealing with the financial and monetary repercussions of climate change. Section 2.3 discusses the nature of climate change risks and argues that new risk management approaches are required to manage climate change risk. Section 2.4 addresses the implications of net-zero commitments for central bank climate policies. Finally, Section 2.5 concludes.

2.2 INCLUDING CLIMATE CHANGE IN CENTRAL BANK MANDATES

The Paris Agreement, a treaty within the United Nations Framework Convention on Climate Change (UNFCCC), had barely been signed by 196 Parties at the 21st Conference of the Parties (COP21) in Paris on 12 December 2015, and ratified on 4 November 2016, when discussions were already under way at several central banks on the implications of this agreement for them. How did this happen?

A link between climate change mitigation and the role of financial markets had already been made for the first time at COP21, in part by associating a grouping of institutional investors to the COP through the Portfolio Decarbonization Coalition (PDC). But it was the landmark speech by the governor of the Bank of England, Mark Carney, that first established a clear connection between climate change and financial stability: "Alongside major technological, demographic and political shifts, our very world is changing. Shifts in our climate bring potentially profound implications for insurers, financial stability and the economy… The challenges currently posed by climate change pale in significance compared with what might come. The far-sighted amongst you are anticipating broader global impacts on property, migration and political stability, as well as food and water security."[30] It was in this speech that Mark Carney first coined the now famous expression, "tragedy of the horizon" (in reference to the tragedy of the commons), to capture the idea that "once climate change becomes a defining issue for financial stability, it may already be too late".

Just over one year after the ratification of the Paris Agreement, the first One Planet Summit was held in Paris in December 2017, with the goal of creating renewed momentum around the breakthrough COP21 and prodding signatories of the Paris Agreement, or new coalitions, to make further bold commitments to combat climate change. It was at that summit that a small group of central banks made a first commitment to address climate change, a commitment that led to the creation of the Network of Central Banks and Supervisors for Greening the Financial System (NGFS). In the October 2018 NGFS report, the network members agreed that "climate-related risks are a source of financial risk. It is therefore within the mandates of central banks and supervisors to ensure the financial system is resilient to these risks." Today the community of central bankers,

30 See Carney (2015).

financial regulators and supervisors accepts that climate change poses potentially systemic threats to financial stability.[31] Recently, as the NGFS has been celebrating its third anniversary, eight new members have joined including the US Federal Reserve System, which means that most major central banks have now joined the network (there are 83 members and 13 observers as of this writing).

This impressively swift reaction by central banks to calls that they needed to use their fire power to help manage climate change risk was far from an inevitable outcome. To be sure, both inside the central banking community and outside, several commentators forcefully argued against embracing a climate change mandate too readily. One prominent example was Jean Tirole, who began his keynote by expressing scepticism about the real achievements of the Paris Agreement: "Governments may also pretend to act when not acting, as when they engage in 'window-dressing' or 'greenwashing'. The acclaimed Paris Agreement embodied only vague promises … following a deliberate strategy to build a consensus among 196 countries on the least-common denominator". Tirole continues by warning independent central banks against mission creep: "Agency independence is not appropriate for broad societal choices, for which the people or its representatives should be sovereign… We must resist this trend of governmental agencies becoming jacks of all trades and masters of none." Yet, he does accept that climate change "already lies within the mandate of central banks: climate change should be embedded in [their] economic forecasts, [their] stress tests, and [their] assessments of collateral accepted by central banks. Climate change will create macro shocks (damages, properties underwater, energy transition, high carbon prices and stranded industrial assets), whose likely size grows everyday as we keep substituting green posturing for actual action."[32]

Another prominent example is John Cochrane, who drew an even sharper line, reacting as follows to the idea that central bank mandates should extend to climate change risks: "These tear to shreds institutional limitations and mandates… To stay independent, trusted, and effective, central banks must be competent, narrow, and boring."[33] By "narrow" he essentially means that central banks should only concern themselves with inflation forecasting and targeting, something macroeconomists have developed some expertise in.

Within the central banking community, Jens Weidmann, president of the Deutsche Bundesbank, has marked out a similar position, writing in a recent editorial: "It is not the task of the Eurosystem to penalise or promote certain industries. … it is not up to us to correct market distortions and political actions or omissions… I very much regret

31 See NGFS (2019a; 2019b).
32 See Tirole (2019).
33 See Cochrane (2020).

seeing often half-hearted climate policies and a lack of credible commitment to a clear transition." He asks rhetorically, "[b]ut should central banks make up for a lack of political will?" Yet, along with Tirole, he does agree that "[c]limate-related financial risks are another factor that central banks need to consider".[34]

These different perspectives shed light on the policy debates on climate change within the central banking community, and where the lines are being drawn. At one extreme are the defenders of central bank independence, and at the other are those concerned with the urgency of the climate crisis and the implications for financial stability. The issue of central banks taking on too much featured prominently in the first report in the Future of Banking series.[35] Indeed, the report expressed concerns that central banks risked losing their legitimacy if overly broad powers were to be delegated to such independent, unelected agencies. This risk is also there when central banks take on climate change risk. Even if central banks have powerful tools at their disposal that could be applied to reverse carbon emissions, they don't have the magic potion to be able to solve the climate crisis on their own. It would be unreasonable to expect that they would singlehandedly take on the challenge of combating climate change. But equally, central banks must be part of the solution. They must play their part along with other actors in the drive to decarbonise our economies. Central bank independence cannot mean that it is acceptable for their policies to be at odds with their countries' net-zero commitments

Huge systemic financial risks will materialise because of climate change, as we illustrate in Chapter 4. Central banks won't necessarily be able to entirely control and limit these risks, but they need to be prepared for the coming climate shocks. Some things they can do are uncontroversial, such as analysing and forecasting the physical, social, economic and financial effects of climate change. But analysis and forecasting on their own won't have much of a real effect. What other policies that have real bite could central banks pursue that fall squarely within their mandate? With the objective of building a broad coalition, that is, naturally, the question that the founders of the NGFS have focused on first. One broad policy suggested by Mark Carney – disclosure of carbon footprints and other climate-related information – has been gaining support, even though determining what to report and how to standardise the reporting is a highly complex task.[36]

Some corporations have already been reporting their carbon emissions over the past decade or so, and several carbon data providers – such as CDP, Trucost, MSCI and Sustainalytics – assemble reported corporate carbon emissions and estimate the emissions of companies that still do not disclose these data. They follow a common Greenhouse Gas Protocol in assessing carbon emissions, which distinguishes between three different categories of emissions: direct emissions from production (scope 1 emissions); emissions from electricity production used by companies in their operations (scope 2 emissions);

34 Jens Weidmann, "How central banks should address climate change," *Financial Times*, 19 November 2020.
35 See Bolton et al. (2019)
36 See Carney (2015).

and indirect emissions in the upstream supply chain caused by input purchases of the company and by the use of the products sold by the company downstream (scope 3 emissions). These are the raw data that can be aggregated to determine the carbon footprint of a portfolio of financial assets.

Still far too few companies disclose their emissions, and even fewer financial institutions report their carbon footprints. Only about 1,700 publicly traded companies around the world have disclosed their emissions in recent years, representing roughly 15% of all listed companies,[37] and even fewer privately held companies have disclosed anything about their emissions. In addition, carbon footprint disclosure in the financial industry is virtually non-existent compared with the carbon disclosure of non-financial companies.

Measuring and reporting emissions is the first step in any attempt to manage climate change risks tied to carbon emissions. Several important initiatives to promote the reporting of carbon emissions have been underway over the past few years. Under the leadership of Mark Carney and Michael Bloomberg, the Financial Stability Board has established the Taskforce on Climate-related Financial Disclosures (TCFD) to consult with institutional investors and companies on how to effectively report firm-level climate risk exposures. Another important recent creation is the Sustainability Accounting Standards Board (SASB), which has a broader aim of defining industry-specific standards to guide the disclosure of ESG metrics. In addition, the International Financial Reporting Standards (IFRS) foundation has begun a consultation process on setting sustainability reporting standards.

Setting standards and achieving broad consensus in the adoption of these standards is obviously a time-consuming process. It is difficult to avoid comparison with financial reporting standards and to expect anything less carefully thought through or of lower quality for climate-related risk reporting. It is always tempting to wait for the data that are needed for rigorous quantitative analysis before acting. Yet, time is running out. The financial reporting systems we have today have been refined over decades, if not centuries. But we only have three decades left to drastically curb carbon emissions and avoid a catastrophic increase in average temperatures beyond 1.5°C or 2°C. We cannot afford the luxury of consulting widely with stakeholders, refining methodologies, and building broad consensus before systematically mandating standardised climate-related financial disclosures.

Both through supervision and regulation, central banks and bank regulatory agencies can accelerate the reporting of both carbon emissions and carbon footprints. What's more, by building on the expertise of carbon data providers and by coordinating their approaches, the members of the NGFS can quickly put in place a global carbon reporting framework. Ideally, corporations would not only be required to report their emissions on an annual basis – as is already the case for companies listed in the United Kingdom

37 See Bolton and Kacperczyk (2020c).

and in some other jurisdictions – but also report future projected emissions up to a three-year horizon as well as their year-by-year commitments to reduce their emissions, in line with the net-zero commitments they themselves, or the countries in which they operate, have made. Similarly, financial institutions should be required to report their carbon footprints on an annual and projected basis, as well as their commitments to decarbonise their portfolios or balance sheets. Given the expertise that providers such as CDP or Trucost have already developed in measuring and reporting GHG emissions, it should be possible to implement systematic reporting of these emissions, reporting of carbon footprints, and reporting of the commitments to reduce emissions within a few years. The sooner these reporting mechanisms are in place, the quicker investors and companies can concentrate their attention on how they will reduce emissions. Five years have already passed since the Paris Agreement and the launch of the TCFD (and nine years since the creation of SASB). It would simply be too late if it took another decade to implement general carbon emission, footprint and commitment reporting.

If generalised reporting of carbon emissions seems within reach, this may unfortunately not yet be the case for the reporting of physical climate risk exposures. As the planet warms and as climate disasters multiply and intensify, companies will increasingly be exposed to losses and disruptions from climate events. Depending on their activities, companies may be exposed to drought, wildfire, flood (and sea level rise), extreme temperatures, and hurricane, typhoon or tornado risks. Studies have shown, for example, how food production is at greater and greater drought risk in many parts of the world, and how food companies' financial performance is increasingly affected by these episodes.[38] The bankruptcy of Pacific Gas & Electric (PG&E) following the 2018 California wildfires it caused is another striking example. How can central banks and investors be more systematically informed about the natural risk exposures of corporations and the financial system? This is not just a challenge for financial reporting but also, and more importantly, for climate change risk management, as we discuss in the next section.

Chapter 4 analyses how physical risks are reflected in company valuations and how large the financial risks related to the physical impacts of climate change can be even for reasonable risk-aversion parameters of investors. By drawing an analogy between a pandemic shock such as Covid-19 and future climate shocks, the chapter highlights both the likely size of the stock market corrections that can occur following a natural disaster and, more importantly, the benefits of mitigation for plausible levels of mitigation investments. The chapter illustrates how efforts to develop a vaccine within a year (rather than the more usual decade for vaccine development) and the news of the vaccine breakthroughs dramatically impacted stock valuations. Investments in pandemic mitigation through vaccine development have turned out to be a very effective risk management policy against the Covid-19 pandemic. When it comes to the rising physical risks of climate change, risk management must also take the form of mitigation

38 See Hong et al. (2019).

(or adaptation) investments. In other words, risk management of physical risks can be seen in a similar way to risk management of transition risk, with mitigation investments (and commitments to mitigation) playing a similar role to carbon emission reductions (and commitments to net-zero targets).

2.3 UNDERSTANDING CLIMATE CHANGE RISKS

Climate change is a source of risks that are fundamentally different from the financial risks investors and financial regulators are used to managing. As Mark Carney emphasised, climate change means that the natural environment is not in steady state. Our natural environment is changing; this change is shaped by how humans interact with nature, and how they are expected to change their attitudes towards a changing natural environment. Climate change is both a natural and a societal phenomenon, requiring an understanding of not just the natural science of how the climate is expected to change and how human behaviour affects these natural changes, but also of social science (how societies around the world are expected to adapt to the physical changes they will increasingly feel and how they will respond to the existential threats posed by global warming).

Stated in such general terms, this seems self-evident. But how will the risks materialise? How will societies, economies and financial systems be affected? How can we frame climate change risks to be able to manage them? Much of the discussion in this section borrows from the *Green Swan* report[39] and subsequent related articles,[40] which call for a thorough reassessment of current risk management approaches to fully apprehend the nature of the risks involved with climate change.

A first reason why traditional risk management practices are inadequate to apprehend climate change risks is that they are based on backward-looking risk assessment models. The premise of these models is that the economy is at or near a steady state, so that future states of the economy can be modelled as deviations of various scale from this steady state (and reversion back to the steady state) under a probability distribution that is estimated from past realisations of economic states. This representation of risks does not come close to capturing the uncertainty we face with respect to climate change, especially over longer horizons. It generally does not allow for model uncertainty (the fact that the model used for estimation may not reflect fundamental aspects of how the economy operates or will continue to operate). And even if model uncertainty can be integrated into the analysis, the models remain highly stylised and do not account for the basic fact that climate change moves us away from anything that could be described as a steady state.[41]

39 See Bolton et al. (2020a).
40 See Bolton et al. (2020b) and Svartzman et al. (2020).
41 See Barnett et al. (2020a).

A second reason why including climate change risk in standard financial risk management models is problematic is that climate change is a certainty according to the climate science today, temperatures will rise inexorably will continue to rise as more CO_2 accumulates in the atmosphere; it is only the timing and the full extent of the physical phenomena it will unleash that are uncertain. Climate change risk increases with the level of carbon emissions, but more emissions today do not immediately materialise as higher risks. However, they set up an irreversible risk that will eventually materialise. Unlike a long position in a risky financial asset, a long position on carbon cannot be unwound; the risk has been irrevocably taken. Barring major technological breakthroughs in carbon capture, the only way to avoid this risk is by simply not going long on carbon in the first place. Risk management therefore cannot be framed as controlled risk-taking, but must be seen in terms of risk avoidance and risk reduction.

A third difficulty with classical financial risk management approaches to climate change risk is that the economic models that are used, which integrate a climate dimension into standard macroeconomic growth models, cannot accurately estimate the expected physical damage from climate change. In his review of these models, Geoffrey Heal explains that "the damage functions of integrated assessment models (IAMs), functions that relate temperature change to economic losses… are supposed to map a change in temperature to a change in welfare, but most of the steps that link the former to the latter are uncertain, some highly so."[42] He further observes that "Nordhaus's DICE model suggests that 2°C leads to a loss of GDP on the order of 1 percent, which is negligible". Yet, "the scientific community's view … is that climate change becomes 'dangerous' above 2°C". Attempts to estimate damage functions with any accuracy have failed, as IAMs are highly aggregated and simplified models.[43] As we have already noted, they simplify the description of the economy to such an extent that they exclude any reference to financial markets, financial crises and financial constraints. But, even worse, IAMs do not integrate any notions of transition risk, chain reactions, social, political, geopolitical risks, and so on. They focus exclusively on physical damages and seek to quantify the economic costs of these damages.

To be sure, IAMs have not been developed with the goal of assisting climate risk management for investors and financial regulators. The first objective was to include climate change in standard macroeconomic growth models and to put a number on the social cost of carbon. Later IAMs have sought to become more realistic and include features that had been left out of the early contributions of William Nordhaus.[44] Yet, as hard as very talented researchers try,[45] ultimately their efforts are constrained by tractability. Quantitative estimation or calibration requires simplification. But the very simplifications that are made generally leave an essential aspect out of the picture. Thus,

42 See Heal (2017).
43 See Stern (2016).
44 Nordhaus (1975; 1977).
45 See, for example, Cruz and Rossi-Hansberg (2020).

from the perspective of financial regulators seeking to manage climate change risks, IAMs are not sufficiently reliable to attempt a quantification of risks similar to current financial risk metrics. A more heuristic and holistic approach is required, and one that takes account of the fact that different risks can materialise at the same time and give rise to complex chain reactions. We argue below that a heuristic approach can be anchored around plausible forward-looking scenarios that articulate pathways for future carbon emissions, mitigation investments and rising temperatures to explore the implications for the economy, financial markets and society of different shocks and chain reactions. But to plausibly define these pathways and sequences of shocks, a holistic analysis of the nature of the physical and transition risks we face, as well as their complex interaction, is necessary.

2.3.1 Green swan events: How interacting physical and transition risks can threaten financial stability

If traditional risk management tools must be discarded, what can replace them? To start with it is helpful to determine a taxonomy of the different risks involved, and to describe in broad terms how these risks may interact. Two main types of risks have been identified: physical and transition risks. Physical risks include the economic and financial losses caused by increasingly frequent and severe weather events, as well as the effects of long-term changes in climate patterns (ocean acidification, rising sea levels, changes in precipitation patterns, reduced biodiversity). As natural catastrophes increase worldwide, non-insured losses to capital, infrastructure and properties (which represent 70% of weather-related losses)[46] will deepen and increasingly upend the livelihoods of households, businesses and even nations. Inevitably, therefore, even financial institutions will be affected. As for insured losses, they will increase the financial fragility of insurers and reinsurers, as compensation claims for damages keep rising.[47] The materialisation of physical risks alone could expose financial institutions to losses that are larger than their capital cushions.

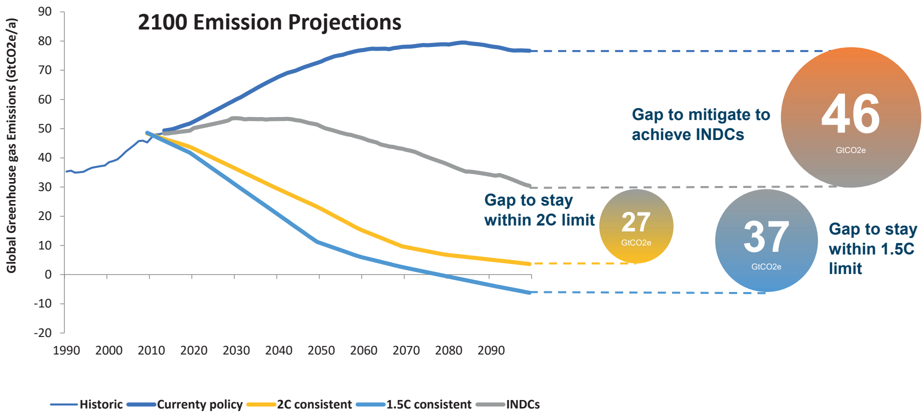
Physical risks will become more severe if carbon emissions are not drastically reduced. The only way to limit exposure to these risks is to drastically decrease carbon emissions. But such a decrease will expose the financial system to another type of risk – transition risk. Broadly defined, transition risks involve any uncertain financial impacts resulting from a rapid shift from fossil fuels to renewable energy, including the introduction of carbon pricing, reputational costs for fossil fuel energy producers and consumers, technological shocks to energy production (from breakthroughs in hydrogen, solar, and wind power, battery technology or carbon capture) and shifts in market preferences and social norms.[48] The structural economic transformation resulting from the steady

46 See IAIS (2018).
47 See Finansinspektionen (2016).
48 See Semieniuk et al. (2020).

reduction in carbon emissions will, in particular, produce a lot of 'stranded assets' in the form of proven fossil fuel reserves that cannot be extracted.[49] The sudden repricing of these stranded assets could by itself be a source of financial instability, giving rise to "climate Minsky moments".[50]

The size of this transition risk is enormous when seen in the context of the numerous net-zero commitments made by government and companies around the world. Essentially, to be able to avoid a temperature rise greater than 1.5°C with a reasonably high probability, the world must eliminate roughly 40 $GtCO_2$/year of GHG emissions by 2050.

FIGURE 1 **GLOBAL EMISSION GAPS**



Note: Time series data for INDCs, 2C consistent, 1.5C consistent time series are computed as medians of highest and lowest potential global emission level results.

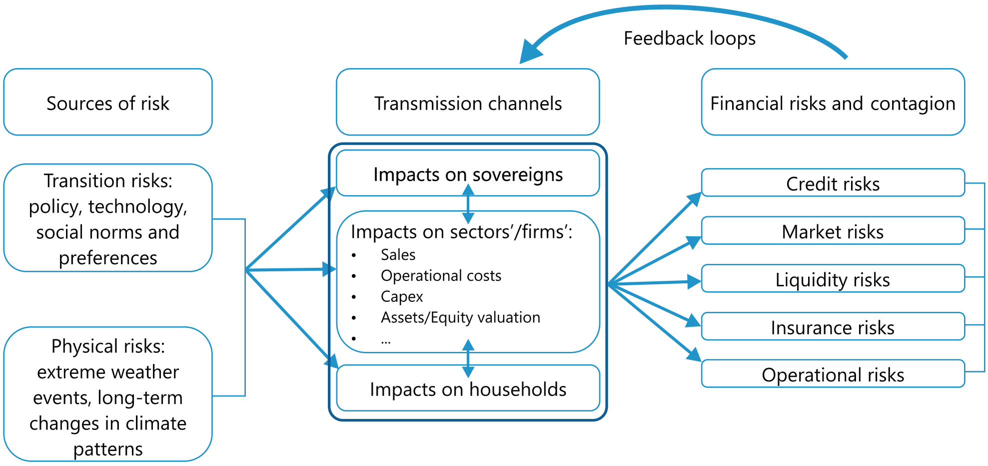
Source: Climate Action Tracker Database, Global emissions time series, updated November 2017. .

This means that from now on, global CO_2 emissions must be reduced by roughly 7% or 8% per year – a rate miraculously achieved in 2020 because of the lockdown measures introduced around the world to contain the spread of the coronavirus. Given the enormous costs incurred in terms of reduced world GDP, increased unemployment and rise in poverty, one can only wonder whether it is realistic for this rate of reduction in emissions to be sustained until 2050.

Over the coming decades, investors will be exposed to both physical and transition risks. Moreover, both types of risk will give rise to chain reactions, as shocks ripple through the economy, society and the financial sector (see Figure 2).

49 See McGlade and Elkins (2015), Matikainen et al. (2017) and Johnsson et al. (2019).
50 See Carney (2016) and Pereira da Silva (2019).

FIGURE 2 **PHYSICAL AND TRANSITION RISK CHANNELS**



Source: Bolton et al (2020a).

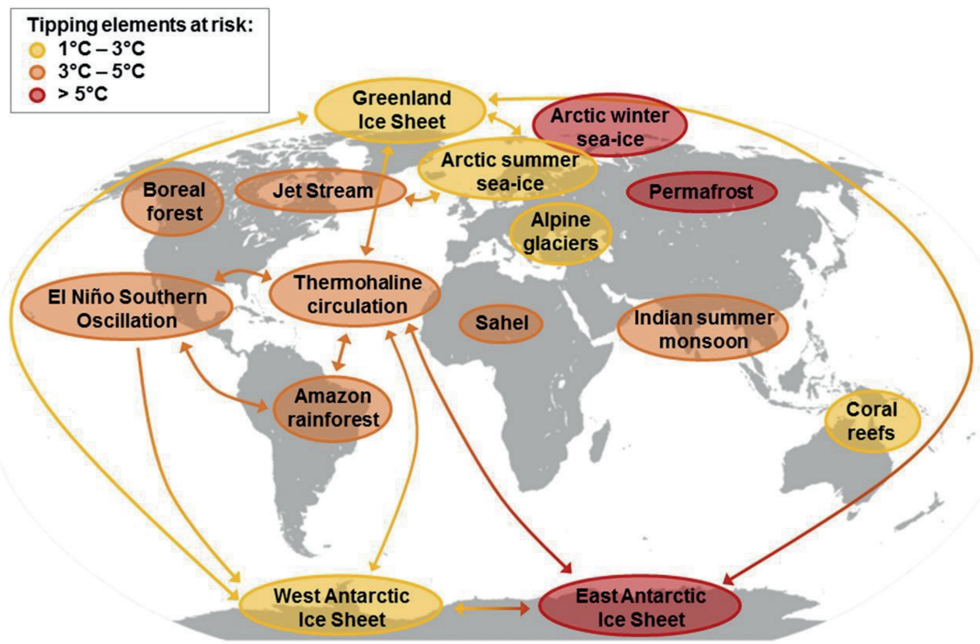
It is the combined realisation of physical and transition risks, and the highly unpredictable knock-on effects they will generate, that constitute a *green swan* event, or series of events. The green swan concept is, of course, an allusion to Nassim Taleb's *Black Swan*,[51] but black swan events differ from green swans in several key respects. Taleb's characterisation of black swan events is that (i) they are unexpected, almost unforeseen by myopic investors; (ii) their impacts are extreme and extensive; and (iii) they can be rationalised after the fact, but risk management tools developed before the event excluded their possible occurrence. Green swans share these characteristics, but also have two additional ones. First, as already noted, the climate science predicts that massive climate shocks are sure to materialise, especially if certain thresholds of CO_2 atmospheric concentration are crossed.[52] Climate-related risks are certain to appear; what is uncertain is when, where and how they will materialise. Second, green swan events could be catastrophic because climate change is irreversible;[53] they may well pose an existential threat.[54]

The complexity of how climate shocks appear and propagate is not just due to the interlocking of physical and transition risks. The physical risks alone are so complex that it is impossible to predict how climate change will affect our natural habitats beyond certain tipping points. Figure 3 offers a very rudimentary but sobering representation of tipping points and the physical risks we are facing in the coming decades if temperatures rise beyond 1.5°C. Warming between 1°C and 3°C could result in the entire disappearance of Greenland's and West Antarctic ice sheets, Arctic summer sea-ice and Alpine glaciers, with repercussions that are difficult to anticipate precisely. Warming beyond 3°C will

51 See Taleb (2007).
52 See, for example, Lenton et al. (2019).
53 As Weitzman (2009; 2011) has emphasised.
54 See Ripple et al. (2017).

upset the Jet Stream, El Niño and Thermohaline circulation, with unknown physical consequences. The radical uncertainty we face over the implications of global warming beyond certain tipping points and the potentially dire consequences for the sustainability of life on earth are such that all efforts must be made to avoid breaching these tipping points. It is hard to conceive of a stronger motivation for the net-zero targets that by now 113 countries have made (representing around 50% of world GDP) and that are intended to avoid an increase in temperatures beyond 1.5°C .

FIGURE 3 **COMPLEXITY OF PHYSICAL RISKS**



Note: The individual tipping elements are colour-coded according to estimated thresholds in global average suerface temperature. Arrows show the potential interactions among the tipping elements that could generate cascades, based on expert elicitation.

Source: Steffen et al. (2018).

There is no point in attempting a cost-benefit analysis for the choice by default (or by neglect) of letting temperatures rise above 2°C. This is the framing of the economic analysis of climate change undertaken by Llavador, Roemer and Silvestre.[55] They consider an optimal growth model, where growth is constrained by an upper bound for GHG emissions: they should not be allowed to exceed total emissions under the IPCC's RCP 2.6 scenario. In other words, physical damages under their analysis are expected to be so high, should we breach the RCP 2.6 scenario level of emissions, that every effort to avoid this outcome is economically justified. This framing is consistent with forward-

55 See Llavador et al. (2015).

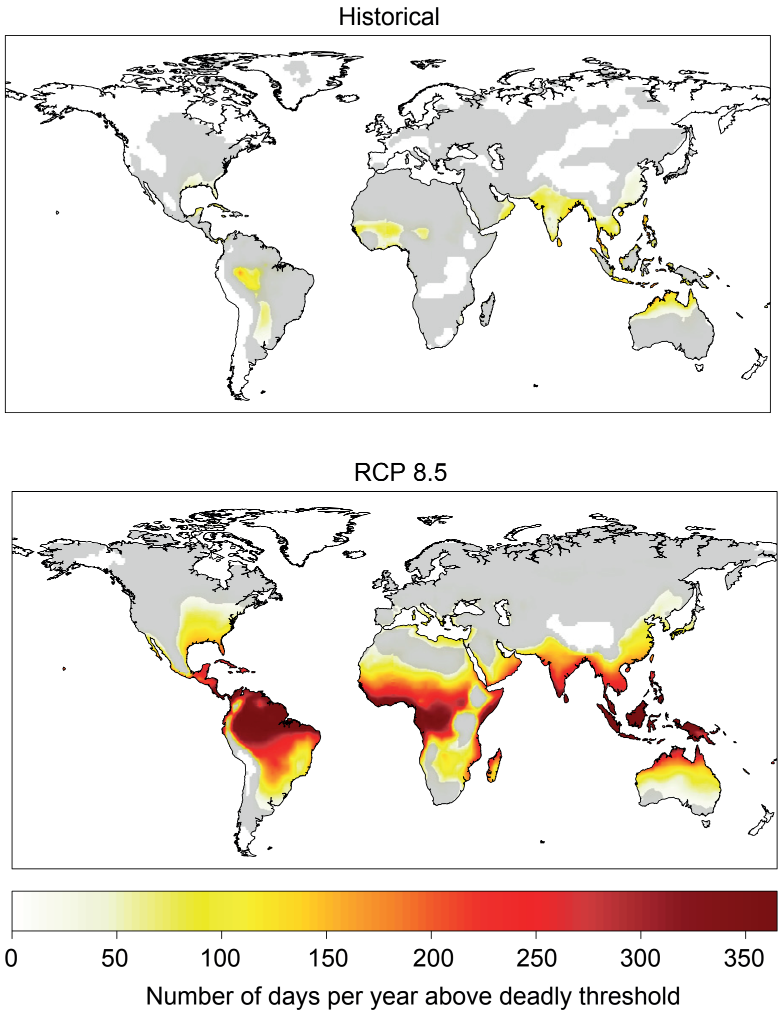
looking scenarios structured around net-zero commitments. The hard questions, of course, are whether these commitments will be met and whether other large economies, in particular the United States, will join in making similar commitments and engage in similar efforts.

Another source of climate risk complexity is the effect on societies of a warming planet and how extreme temperatures will give rise to geopolitical risks, the full ramifications of which are impossible to predict. The modelling of the effects of rising temperatures in IAMs is far too reduced-form; average temperature increases do not just result in lower productivity. Rising temperatures for countries in the most vulnerable areas will bring about systemic social and economic changes that could result in failed states and other breakdowns. Consider the map of the world with extreme temperatures and humidity episodes in Figure 4. Under a business-as-usual scenario, extreme temperature and humidity episodes in large parts of the world will be so prolonged and severe by the end of the century that these regions will become uninhabitable. If you look at the most affected regions in Africa, you see that large parts of the most populous regions in Africa will become uninhabitable. By 2050 Nigeria will have a population of similar size to the United States, yet large parts of Nigeria will by then be uninhabitable: "Heatwaves, which caused 91 percent of extreme temperature deaths in the past two decades, will be especially pronounced in Africa, where almost one billion people face a high risk of heat stress.... In densely populated lower-income countries close to the equator, with weak economies, inadequate roads and power supplies and other infrastructure deficiencies, climate risks could lead to food shortages, mass migrations and other social challenges."[56] Even if the World Bank Group's estimate that "[b]y 2050, climate change could force more than 143 million people in just 3 regions to move within their countries" is not surpassed (as it may well be), this would result in a major geopolitical shock with incalculable consequences for political, economic, social and financial stability.

A full understanding of the physical risks of climate change must obviously include an analysis of the possible effects on society and on geopolitical stability. Even if the physical effects of warmer temperatures can ultimately be traced to a cost in terms of loss of productivity and loss of financial value, it is a great oversimplification to merely model the ultimate effects on productivity and stock valuations. Keeping track of the possible effects on society is important if only to be able to assess how these physical effects can be mitigated, what mitigation investments are needed, and what societies can do to adapt and transition to more sustainable lifestyles.

56 Yaryna Serkez, "What Are the Top Climate Threats in Your Country?", *New York Times*, 28 January 2021.

FIGURE 4 **EXTREME TEMPERATURES AND HUMIDITY**



Source: Global Risk of Deadly Heat (*Science* 2017)

Finally, the transition to renewable energy depends fundamentally on technological progress, and despite the enormous advances in renewable energy over the last two decades, there is still a lot of uncertainty around the pace of innovation going forward, in particular around technological breakthroughs in batteries and electricity storage. In its special report on clean energy innovation, *Energy Technology Perspectives 2020*, the IEA estimates that if the pace of innovation is faster than in the Sustainable Development Scenario, then "CO_2 savings from technologies currently at the prototype or demonstration stage would be more than 75% higher in 2050 … and 45% of all emissions savings in 2050 would come from technologies that have not yet reached the market".[57]

57 See IEA (2020).

Yet the report also underscores the extent to which this may be pie in the sky: "Such rapid deployment would require successful innovation cycles that are more rapid than any seen in recent energy technology history. Key clean energy technologies at demonstration or large prototype stage today would need to reach markets in six years from now at the latest, which is twice as fast as in the Sustainable Development Scenario." What if the anticipated innovations do not materialise? This could by itself result in a systemic shock, if most net-zero commitments are based on innovation assumptions that prove to be too optimistic ex post.

2.3.2 Forward-looking scenarios and radical climate uncertainty

The complexity of the risks posed by climate change – the natural, social, economic, political and financial dimensions involved – imply that central banks need to make holistic, open-minded, interdisciplinary risk assessments, and they need to make sure that climate-related risks are appropriately understood by all players.[58] A consensus has quickly emerged in the NGFS that a good basis for such an approach would be forward-looking scenario building, which allows for a versatile analysis that at the same time cuts through the complexity of making reliable probability assessments.[59] Forward-looking scenarios are a humbler approach to risk management than current financial risk management methodologies based on quantitative models; they only seek to define plausible hypotheses for the future, and they accept the fact that climate risks are not always reliably quantifiable.

The notion of forward-looking scenarios is simpler to conceive of in the post-global financial crisis era, when stress tests have become common practice for assessing the vulnerability of financial institutions, and of the financial system, to a sudden recession or financial shock. To be sure, there have already been calls to develop 'climate stress tests'.[60] Battiston (2019), for example, has built forward-looking scenarios on existing IAM models to assess the exposure of financial institutions to sectors that are particularly vulnerable to transition risks. Some central banks have also developed their own forward-looking scenario analyses.[61] The Banque de France, for example, has developed a framework to determine the potential impacts of different low-carbon transition scenarios (including sudden increases in carbon prices) on specific macroeconomic and sectoral variables.

As natural as the analogy between forward-looking scenarios and stress tests is, it is important to underscore that these are not the same exercise. For one, the horizons for stress tests and forward-looking scenarios are not the same. Stress tests are very short-term assessments, whereas forward-looking scenarios must inevitably be more long-term due to the more long-term nature of the risks. Under most forward-looking scenarios there are hardly any significant losses expected in the short run, yet a long position on

58 See NGFS (2019a).
59 See Batten et al. (2016), NGFS (2019a), Regelink et al. (2017) and TCFD (2017).
60 See, for example, ESRB (2016), Battiston (2017), Battiston et al. (2019) and Regelink et al. (2017).
61 See Allen et al. (2020), EBA (2019), EIOPA (2019), PRA (2019), and Vermeulen et al. (2018; 2019).

carbon today almost surely translates into the materialisation of a cost sometime in the future. This cost may not necessarily be borne by the financial institution, but certainly by society at large and the financial system. Accordingly, risk cannot be measured simply through the lens of profits and losses within a one- or two-year horizon at an individual financial institution. It must be measured more directly through exposures to carbon emissions (carbon footprints), and by testing the financial repercussions of reducing these exposures for the whole financial system and the whole economy.

Integrated assessment models have proved to be useful to structure forward-looking scenarios. But, as we have already noted, they are not well suited to address the complexity of the risks involved, nor the radical uncertainty we face when tipping points are crossed.[62] To give just one relevant example of an amplified risk from climate change, Legendre et al. (2015) warn us that the melting of the permafrost could cause new pandemics, with far more devastating effects than the Covid-19 pandemic.[63] Such possibilities are left out of IAMs but should naturally be considered in forward-looking scenarios.

Another difficulty with an IAM-anchored forward-looking scenario approach is that IAMs are typically models of rational agents and efficient markets, which do not adequately reflect the reality of irrational agents (among which are many climate-change deniers), and inefficient and incomplete markets. What's more, individual agents in IAMs are assumed to make decisions in isolation in response to market signals, and any social interactions, changing social norms of behaviour or collective actions are entirely abstracted from. Yet, an important input into forward-looking scenarios is how societies will perceive climate change and how they will react to the apparent threats of climate change. One key aspect of changing social behaviour is the adoption of more sustainable lifestyles and the increasing use of renewable energy.[64]

The technologies that will dominate in a low-carbon economy remain subject to deep uncertainty.[65] An optimistic scenario[66] is the rapid development of renewable energy technologies that can meet the energy demand of a growing global economy. But such technological breakthroughs may not appear soon enough, so other mitigation scenarios must be envisaged where the focus is on reducing energy demand or on scaling up carbon capture technologies, with again the risk that these technologies, which are still at an early stage of development, may not be able to deliver on their promise.[67] This technological uncertainty makes it even more difficult to assess the risks and opportunities associated with the transition to a low-carbon economy.

62 As the IPCC (2018), Lenton et al. (2019), and Steffen et al. (2018), among others, have pointed out.
63 See Legendre et al. (2015).
64 See Curran et al. (2019).
65 As Barreto and Kemp (2008) forcefully argue.
66 As described by the IEA (2020).
67 See Carbon Brief (2018).

An IAM-anchored forward-looking scenario, because it presumes a competitive market economy where market prices efficiently coordinate actions, will tend to be biased towards market-based solutions to internalise externalities that involve, one way or another, markets for emission permits or carbon pricing. But in reality, market adaptation comes with duplication and delay, and in situations of urgency such as wars or pandemics, a quantities-based planning solution that avoids unnecessary delay and duplication gets closer to the social optimum.[68] Some form of carbon pricing is, of course, a critical step in weaning companies and consumers off fossil fuels. But reliance on carbon prices alone to guide the massive structural change necessary to achieve net-zero emissions by 2050 is unlikely to be effective. Indeed, as Hepburn, Stern and Stiglitz have argued, "many structural challenges such as the design of cities, industrial supply chains and production networks, respond weakly, or slowly, or both, to marginal price changes".[69]

Forward-looking scenario analysis must also be open to the emerging approaches of systems modelling and complexity science.[70] Systems modelling emphasises critical network links and the structure of a system,[71] while complexity science studies properties of interactions between system components.[72] These approaches feature prominently in the field of ecology, but they have also been applied to other fields in sociology[73] and economic and financial systems.[74] Non-equilibrium models, such as agent-based models (ABMs), stock-flow consistent models (SFCs) and network models,[75] are examples of systems-modelling approaches. Such models can better capture some key features of climate-related risks involving chain reactions and path-dependency. In a way, the current economic system, with out-of-control carbon emissions, can be thought of as a non-equilibrium model involving long-term and uncertain dynamics, interactions among multiple agents and potential structural or systemic changes.[76]

Agent-based models and non-equilibrium models naturally lend themselves to scenario analysis.[77] Chain reactions and propagation channels of climate shocks can be modelled in this way.[78] One example is modelling how stranded assets in one sector can lead to a "cascade of stranded assets" in other sectors.[79] Another example is modelling how a climate shock can propagate through financial exposures.[80] Monetary and financial transmission channels can also be studied using non-equilibrium models.[81]

68 See Bolton and Farrell (1990).
69 See Hepburn et al. (2020b).
70 These approaches are closely related, as Arnold and Wade (2015) argue.
71 See Capra and Luisi (2014).
72 See Mercure et al. (2016).
73 See, for example, Capra and Luisi (2014).
74 Notably by Taleb (2007).
75 For example, Lamperti et al. (2019).
76 See Hepburn et al. (2020b), Lamperti et al. (2019), Mercure et al. (2016) and Monasterolo et al. (2019).
77 See Monasterolo et al. (2019).
78 As in Semieniuk et al. (2020).
79 See Cahen-Fourot et al. (2019). They show that although the mining sector represents a relatively small share of value added, a stranded asset shock in this sector can have systemic effects since it supplies essential inputs to many downstream sectors.
80 See Battiston et al. (2017).
81 See Espagne (2018), Mercure et al. (2019), and Svartzman et al. (2019).

Yet, even agent-based and non-equilibrium models which are highly versatile may have their own limitations. They are suitable for modelling predictable economic links in a network, but less so for capturing behavioural or social changes in the adaptation to climate change and the energy transition. To incorporate these dimensions, one must turn to socio-technical transition analyses,[82] where a given socioeconomic environment is described by “the conventions, rules, and norms that guide the uses of particular technologies and the everyday practices of the producers, workers, consumers, state agencies, scientists, societal groups, and business people who participate in the regime”.[83] Socio-technical transition analyses study the interactions between technological change and the social conventions (rules and norms) that govern the use of new technologies. They have, for example, highlighted the difficulties in predicting which low-carbon transport technologies will prevail without knowledge of the broader social norms towards car sharing, public transportation and changes in cultural attitudes towards car and durable goods ownership, or towards urban sprawl.[84] Social norms do not just affect how we travel or how goods are transported and where we live. Entire lifestyle changes are needed, and to be expected, in the transition to economic sustainability.

Social transition and adaptation are not merely about individual lifestyles; the norms of the corporate sector can also be expected to change, as the current debates around the purpose of the corporation reveal. We are already seeing a fundamental shift towards responsible investment, and greater attention being paid to the ESG impact of economic activities.[85] These are deep, slow-moving transformations that will reshape the corporate sector and introduce more sustainable models of economic production and activity.

A fundamental issue is in the balance with these socioeconomic considerations around sustainable energy consumption. Will sustainability targets conflict with economic growth? If carbon emissions are to be brought in line with net-zero commitments, does that imply that GDP growth will be lower, or even negative, as was the case in 2020 as a result of the pandemic? Is ‘degrowth’ a corollary to the energy transition? If we cannot achieve decarbonisation through innovation, we may have no choice but to reduce our energy consumption and to degrow our economies. This could open up a dilemma for central banks, should their mandates on price and financial stability conflict with the goal of reducing climate risk.[86]

Socio-technical transition analyses can also be extended to analyse the geopolitical dimensions of climate change and the transition to renewable energy. Extreme temperature and humidity episodes, flooding and hurricanes, droughts and wildfires will cause mass migration, thereby politically destabilising entire regions.[87] How will these changes affect economic and financial stability? The transition away from fossil fuels will

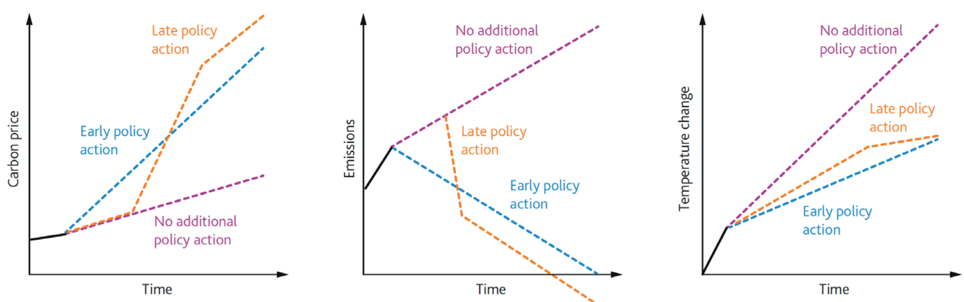
82 As, for example, in Geels et al. (2004; 2016; 2017).
83 Lawhon and Murphy (2011, p. 357).
84 See Mattiolie et al. (2020).
85 See, for example, Mayer (2013) and Eccles and Klimenko (2019).
86 See Jackson (2017) and Naidoo (2020).
87 See Abel et al. (2019), Bamber et al. (2019), Kelley et al. (2015) and McNamara et al. (2018).

also affect the balance of power between states, reconfigure trade flows, and transform the nature of existing conflicts, with perhaps fewer oil-related conflicts but possibly more conflicts over access to essential minerals for batteries and other renewable energy technologies.[88]

2.4 CENTRAL BANK CLIMATE POLICIES IN THE CONTEXT OF NET-ZERO COMMITMENTS

In light of the discussion of climate change risks above, it is not surprising that the first major policy initiative on climate change by several central banks has been the definition of forward-looking scenarios and climate stress tests. Building on NGFS reference scenarios, the Bank of England has elaborated a climate stress test – the Biennial Exploratory Scenario (BES) – which will be conducted for the first time in 2021. Under this test, the Bank of England will ask all the major UK banks and insurers to estimate the size of their climate risk and carbon exposures under three scenarios over a 30-year time horizon: an *early policy action scenario*, a *late policy action scenario* and a *no additional policy action scenario*.[89] In each scenario the Bank of England specifies a reference pathway for a carbon price, carbon emissions and average temperature change. Banks are then asked to quantify the risks they face under each scenario. They do this by asking in turn their major corporate clients to quantify their risks and by aggregating this information into a carbon footprint of their balance sheets and other risk exposures, which they report back to the Bank of England. Banks are also required to ask their major corporate clients (large firms) what actions they plan to take to mitigate these risks, and what their proposed carbon emission reduction pathways are under each scenario. The logic behind these three scenarios is to identify not only the size of climate risk exposures in the banking and insurance sectors, but also the extent to which an orderly transition path, with early action, is feasible.

FIGURE 5 **BANK OF ENGLAND SCENARIO PATHWAYS**



Source: Bank of England (2019).

88 See IRENA (2019).
89 See Bank of England (2019).

A first major benefit of this BES exercise is to provide granular information about climate risk exposures at the firm and financial institution level. A second benefit is that the BES sets up a consistent methodology for assessing transition paths and risk assessments at the firm level. It is a form of 'indicative transition planning', which is necessary given that there are no market signals to guide individual corporations' and banks' actions. Corporations and financial institutions, along with central banks, are struggling with climate risk management and with establishing climate risk management methodologies. The scenario pathways defined by the Bank of England help financial institutions to define a set of benchmarks against which they can assess the climate risk exposures of their corporate clients. Finally, the BES has the benefit of simplicity. It does not seek to implement a complex agreement among all carbon emitters on who contributes what and when. It simply asks what the current level of carbon emissions is at the firm and bank level, how firm-level emission reduction pathways align with the Bank of England scenarios, and what the costs are likely to be for firms to reduce their emissions along a particular pathway.

It is natural for central banks to take the lead in providing this form of indicative planning, as they have already gained considerable expertise in running stress tests. In addition, the transition to net zero must go through financial markets, and financial institutions must guide the reallocation of capital needed to move towards a green economy. Through their forward-looking scenarios, central banks can help coordinate investments and this reallocation of capital. A key role that central banks already play is with forward guidance and with forecasting economic activity, inflation and underemployment. When it comes to climate change and the energy transition this role is vastly expanded, as central banks will need to forecast further into the future and they will need to provide forward guidance on more than just interest rates. Importantly, through the NGFS central banks can coordinate around a global approach to guiding the reallocation of capital towards renewable energy. To be sure, if the transition to net zero is to be successful, it must be a global transition. If only a small group of countries embark on a pathway to reducing their carbon emissions to net zero, their efforts will have a limited effect in slowing down global warming. It is encouraging in this respect to see that other major central banks are following in the footsteps of the Bank of England, among which are the Banque de France, the Australian Prudential Regulation Authority, De Nederlandsche Bank, the Bundesbank and the European Central Bank.

If bank supervision policies around forward-looking scenarios are a natural first step, it is less clear what central banks should do next or in addition to running climate stress tests. Many different policies have been evoked, but there is less consensus in the central banking community around these policies than around forward-looking scenarios. Another general policy direction that is relatively uncontroversial and that is consistent with the conduct of climate stress tests is mandatory disclosure of carbon emissions, carbon footprints and other material climate-related risk exposures. As we have already noted, the standardised reporting of physical climate risk exposures is technically challenging and may not be immediately feasible. But for carbon emissions – the best and most direct measure of transition risk exposures – standardised reporting is much more advanced, and indeed several countries already mandate the disclosure of carbon emissions. Therefore, a priority for the coming years should be to systematise carbon (footprint) disclosures and to extend disclosure mandates to as many countries as possible.

Once carbon emissions and carbon footprints are systematically reported at the firm level, it is much easier to monitor the year-by-year progress of companies in reducing their emissions, and the progress of financial institutions and asset managers in decarbonising their portfolios. There has always been a concern with 2050 – or sometimes more ambitious 2040, or even 2030 – net-zero commitments that the somewhat distant future target is an easy way of buying time while appearing virtuous. How do we know that these net-zero commitments are achievable, and whether actions are already being taken to ensure that the net-zero target can be reached? A common reaction from corporations is that it is difficult to translate carbon emission reduction policies into year-by-year emission reduction targets. Companies are bound by contractual commitments, production technologies in place, and other operational constraints that make it difficult to commit to significant reductions in emissions in any given year, even if they can plan for significant reductions by a given target year. Companies need flexibility, yet there is a real risk that the more room for manoeuvre companies have, the easier it is for them to postpone the painful adjustments.

Does this mean that tracking year-by-year emission reductions is pointless? One way of answering this question is to see how stock returns are affected by year-by-year changes in emissions. Looking at a comprehensive global sample of publicly listed companies, Bolton and Kacperczyk find that, other things equal, companies that were able to reduce their emissions over a one-year period are associated with lower expected returns.[90] That is, companies that have reduced their emissions benefited by being able to lower their cost of capital. Investors understood the reductions in emissions to mean that the company is less exposed to carbon transition risk, and therefore they were willing to hold the stock for a lower expected return. This evidence suggests that stock investors do increasingly worry about year-by-year changes in emissions and take further growth (or no reduction) in emissions as a red flag. If investors do worry about the year-by-year rate of reduction in emissions, it seems logical that financial regulators and central banks should too. Hence, the periodic implementation of climate stress tests anchored around forward-looking scenarios and net-zero targets could be used to monitor period-by-period progress in cutting emissions, thereby reducing the risk that companies and financial institutions will do too little too late.

90 See Bolton and Kacperczyk (2020b).

If the discipline imposed by investors is not sufficient to reign in carbon emissions, should central banks go beyond supervision, climate stress tests and carbon footprint disclosure, and envision some form of climate prudential regulation? If so, what form should these regulations take? These questions are currently being debated in the central banking community. Some form of regulatory intervention to induce banks to limit credit to companies with high emissions would certainly give more teeth to central bank climate risk management. However, in the current environment of low or negative interest rates and sluggish economic activity, the difficulty with additional capital regulations is that banks could be discouraged from lending altogether. The challenge with any climate regulatory intervention is to effectively *shrink* bank carbon footprints and other climate-related risk exposures while maintaining banks' incentives to lend. Regulatory changes that do not add to banks' overall regulatory capital requirements but reallocate capital requirements towards assets associated with high carbon emissions and away from assets with low or no carbon emissions could achieve the right balance.

For example, the risk-weighting of assets methodology could be modified by adding a carbon-weighting of assets component. As Bolton and Kacperczyk have shown, total firm-level carbon emissions (both direct and indirect), as well as year-by-year changes in emissions, are positively correlated with expected stock returns (other things equal), indicating that investors perceive these companies to be riskier.[91] Hence, adding a carbon emission weight to the weighting of bank assets for capital regulatory purposes could be an effective way of tilting bank incentives away from brown assets to green assets. And if both direct and indirect emissions are used in the carbon-weighting of assets, then companies that consume a lot of fossil fuel would be penalised as much as companies that extract a lot of fossil fuel.

Similarly, once the periodic conduct of climate stress tests is in place, central banks could tie bank dividend payments to passing the climate stress test. A bank that is found to be on a carbon footprint pathway that is incompatible with achieving the net-zero target is adding risk to the banking system, which would justify a suspension of dividend payments. Bank resolution policies could also be adjusted to reflect climate-related risks. Systemically important banks are required to file resolution plans (so-called 'living wills') that help both in the identification of potential risks and in the planning for the orderly liquidation of assets and 'bail-in' of TLAC liabilities in the event of a large loss. These resolution plans could be augmented with 'stranded asset scenarios' (losses incurred in the event of a sudden collapse in oil and other commodity prices) and systemically important banks could be asked to plan for the potential liquidation of assets exposed to stranded asset risk.

91 See Bolton and Kacperczyk (2020b).

Physical climate risk exposures could be treated in the same way, although of course risk measurement is substantially more complex given the highly heterogeneous nature of physical risks. Assets that are currently exposed to drought or flood risk will certainly see these risks rise with global warming. Hong, Li, and Xu have shown that company exposures to drought risk can be estimated by using the Palmer Drought Severity Index (PDSI) and that investors underestimate the rate at which drought risk is rising as a result of climate change.[92] Weighting assets with the PDSI could induce banks to take better account of future drought risk exposures and help accelerate necessary adaptation efforts and mitigation investments. Similar research is underway to develop a Flash Flood Severity Index (FFSI), and eventually such an index might become available to measure exposures to rising flash flood risk in a more systematic way.[93]

A more difficult and controversial question is whether climate change risk considerations also touch on the conduct of monetary policy and the management of central bank reserves. Should monetary policy be modified in the face of the looming climate crisis? A longstanding principle of monetary policy is that a central bank should not intervene in resource allocation or in direct lending. Central banks should confine themselves to supporting the lending activities of banks, who are better informed about which loans have a positive net present value and about whom to profitably lend to. Central banks are the bank of banks, providing liquidity to banks and sometimes intervening as lender of last resort. And central banks should confine themselves to controlling inflation and aggregate economic activity. By this principle, central banks should take a neutral stance in their collateral frameworks and in the management of their reserve assets.

The issue with this general monetary policy neutrality principle when it comes to climate change, however, is that as a result both the eligible collateral and the composition of reserve assets naturally reflect the current composition of assets in the economy, which historically has been, and still is, dominated by brown assets. In other words, by applying this neutrality principle, central banks are by default tilted towards assets from companies associated with high carbon emissions, whether direct or indirect. What's more, collateral eligibility criteria are primarily based on credit risk and credit quality, further tilting the composition towards blue-chip companies, which are more deeply associated with high carbon emissions. Hence the question of whether central banks should overhaul their collateral frameworks and collateral eligibility criteria to take account of climate change risk. The same question applies to the management of their reserve assets and to the management of the assets of sovereign wealth funds.

Central banks are naturally wary of going against the monetary neutrality principle. They also worry that by discriminating between assets based on criteria other than credit quality, they may be drawn into intervening more directly in the economy, and by doing so may put their independence at risk. Yet, the status of central banks as independent

92 See Hong et al. (2019).
93 See Schroeder et al. (2016).

government agencies does not put them above government. Even as independent agencies, their actions must be broadly consistent with the policies and commitments made by their governments. Accordingly, they must act in a manner that is consistent with the net-zero commitments of their governments. They cannot act in a way that undoes other government policies to reduce carbon emissions. This means that when it comes to collateral frameworks and reserve asset management, central banks need to align their policies with the broader net-zero commitments of their countries.

But even abstracting from these considerations, central banks will be more credible and effective prudential regulators if they practice what they preach. If they demand that the financial institutions they supervise report their carbon footprints and their pathways towards decarbonisation, they ought to be consistent and report the carbon footprints of their eligible collateral and reserve assets along with them. Moreover, they ought to report how they plan to decarbonise their own portfolios. Some central banks have already begun implementing the first steps of these policies. Thus, the Riksbank is now applying sustainability criteria to its foreign exchange reserves by selling off bonds emitted by subnational Australian and Canadian authorities that are highly exposed to carbon-intensive operations.[94] Similarly, the Bank of England is actively considering how to include sustainability criteria in its unconventional asset purchases.[95] The European Central Bank has decided that bonds with payment terms linked to sustainability performance metrics would become eligible for both conventional and unconventional operations.[96]

Finally, central banks must also engage with other arms of government in coordinating their climate change mitigation policies. They cannot content themselves with developing forward-looking scenarios and implementing climate stress tests, and then simply wait for other arms of government to act. Such a passive stance could expose them to the real risk of not being able to deliver on their mandates of financial stability or force them into unnecessary LOLR interventions. Central banks can play a more proactive role in calling for broader and coordinated climate change mitigation policies. They can begin by coordinating their own climate risk management policies globally. They can also engage with the financial industry and institutional investors in promoting common and coordinated approaches to achieving net-zero commitments.

2.5 CONCLUSION

The coronavirus pandemic has powerfully brought home the all-too-quickly-forgotten reality that nature can strike back. What epidemiologists had long feared, and what Bill Gates had forewarned in 2017 – “whether it occurs by a quirk of nature or at the hand of a terrorist, epidemiologists say a fast-moving airborne pathogen could kill more than

94 See Flodén (2019).
95 See Bailey (2020).
96 See ECB (2020b).

30 million people in less than a year"[97] – eventually came to pass. Most countries did not immediately take the measure of the pandemic risk they were facing, and several countries minimised the problem even as the pandemic was raging. The response to the natural disaster was similar in this respect to the first responses to the global financial crisis. When the crisis hit, inertia, political ideology and sheer hubris prevented a forceful early response to quell the pandemic and limit its public health and economic fallout.

Will the coronavirus pandemic transform our economies, our attitudes towards protecting nature and preventing climate change, in the same way as the global financial crisis has profoundly reshaped our financial system, the way it is regulated and the role of central banks? Far from distracting attention away from combatting climate change, the pandemic has reinforced concerns about the sustainability of an economic model that is exclusively oriented towards increasing growth and consumption – an economic model with incomplete markets and incomplete property rights, and with no mechanisms to protect nature, biodiversity, the climate and the future sustainability of our subsistence on earth.

Will these concerns give rise to a new, more sustainable economic model? Public opinion in many parts of the world has already started to shift, and new green political coalitions have been successful in pushing for the implementation of 'green recovery plans' in several countries. But these recovery plans have not yet been implemented. Even if they succeed in bringing the economy back to full employment, as they are designed to do, they could fail in sufficiently containing carbon emissions. This is an important endogenous systemic risk that central banks need to prepare for. They may need to prepare for the dilemma they could end up facing between saving the planet or saving the financial system.

97 Bill Gates, "A new kind of terrorism could wipe out 30 million people in less than a year – and we are not prepared", *Business Insider*, 18 February 2017 (www.businessinsider.com/bill-gates-op-ed-bio-terrorism-epidemic-world-threat-2017-2?IR=T).

CHAPTER 3

Asset managers' response to natural disasters

3.1 INTRODUCTION

The risks involving natural disasters and climate change are large and complex. As such, they require a broad range of players and tools to manage them. In our discussion so far, we have highlighted the importance of public institutions, such as governments and central banks, in this role. This chapter focuses instead on the private sector as a natural complement in the risk management process, with a special emphasis on one of the most powerful and wide-reaching actors, namely, asset managers. The discussion in this chapter centres around two complementary sets of managerial activities: hedging and engagement in mitigation. Together, they are meant to facilitate resilience.

Among its many functions, the asset management sector is an intermediary connecting households' investable savings with financial markets offering a return premium on the invested capital. It is also an efficient medium which supports the provision of capital for production. In the post-global financial crisis period, the sector has witnessed a rapid growth in its size, reaching about $100 trillion in assets under management globally, which dwarfs the size of the entire banking sector. This growth was accompanied by a large concentration of assets among a few dominant players. Not surprisingly, many pundits have pointed to the sector's systemic importance in financial markets.

A parallel and fairly recent phenomenon has been a shift in capital allocation towards ESG considerations. This process has been further amplified by the unfolding climate crisis and the recent Covid-19 pandemic. One of the main actors in this transformation have been asset managers. Their role has been manifested in various forms, including active and passive management of ESG-driven financial assets, direct involvement in shaping corporate culture in the real economy and shaping broader social norms. Through their fiduciary duties, asset managers serve a large part of society and are responsible for managing its exposure to natural disasters and climate change risk. At the same time, given their expertise, asset managers are well positioned to anticipate the occurrence and consequences of natural disasters. It is fair to say that asset managers play a dual role in society: they protect the wealth of their individual clients, and they have the power to have an impact on the engagement of broader society. This chapter seeks to understand asset managers in their role of building individual and social resilience.

The chapter lays out the framework to address this problem, pointing to three pillars of effective risk management. The first pillar involves asset managers seeking welfare protection through the use of various hedging instruments. Under this theme, a few questions are particularly relevant. What is the role of hedging strategies? How should one think of hedging in the presence of systematic versus idiosyncratic risks? How does the persistence of shocks affect such strategies? The second pillar involves any engagement activities of asset managers aiming to reduce the production of negative externalities. Here, the main questions of interest are: What is the relative importance of divestment and activism? What other actions taken by asset managers can stimulate the mitigation efforts by the real sector? How should the asset management sector incentivise their managers to exert effort in this regard? The third, and the most overarching, aspect of risk management emphasises the broad implications of the mitigating actions for market efficiency and welfare.

The chapter provides a comprehensive perspective on the above issues. The main ideas are mostly discussed in the context of climate risk because this setting offers a broad spectrum of interesting considerations to focus on. However, many conclusions naturally apply to other similar contexts. The specific discussion is divided into five parts. Section 3.2 presents broad underpinnings of the asset management sector. The focus here is on three elements of investing world: delegated asset management, social value consideration and general equilibrium forces. Section 3.3 studies resilience issues through the lens of hedging activity. The hedging process is cast in a simple cost-benefit framework. Specifically, the section presents various factors that mediate this process, including the nature of the risks, the investment horizon, the persistence of shocks and their observability. Section 3.4 discusses two types of actions that financial sector can take to mitigate natural disasters and climate risk. The first are demand-driven disciplinary actions that trigger reductions in GHG emissions of other market participants. The primary examples of such actions are divestment and activism. Important for such actions are the underlying contracting framework and its dynamics supported by the rise of the ESG phenomenon. The second type are supply-driven actions that support direct mitigation, such as financing of green (environmentally friendly) investments. Section 3.5 discusses spillovers from the asset management sector to other parts of the economy. Here, attention is paid to the role of asset managers in reaching market efficiency. The concluding Section 3.6 summarises the main policy-relevant takeaways and discusses potential limitations of building resilience through the asset management sector.

3.2 THE ASSET MANAGEMENT PARADIGM

In its simplest form, asset management is an application of two seminal theories: the portfolio theory of Markowitz and the capital asset pricing model (CAPM) of Sharpe. The portfolio theory postulates that investors choose portfolio weights that maximise their expected future wealth or consumption subject to a host of investment constraints. A special case of this optimisation problem is the mean-variance utility framework, in which portfolio weights are chosen to maximise the trade-off between expected returns on a portfolio and the portfolio's risk for a given level of investors' risk aversion. The CAPM further asserts that investors should hold a portion of their assets in the market portfolio, thus giving rise to passive management. This notion is further extended by Grossman and Stiglitz into a framework with asymmetric information, thereby allowing for the presence of both active and passive investors.

While the above contributions offer a close approximation of the non-intermediated investing reality, they do not provide a fully accurate description of asset management in which delegation of capital by outside investors plays a crucial role. Accounting for the delegation feature in the portfolio theory expands the conceptual framework in a nontrivial way. Most important is the agency relationship between the end investor and the asset manager. Briefly, agency becomes particularly relevant when investors' objectives do not coincide with those of managers, but even more broadly, it imposes discipline on the actions that asset managers can take when forming their portfolios. Further, the presence of agency is particularly important when thinking about the resilience of the sector to large shocks and natural disasters, in particular.

Apart from the delegation aspect, managing risks arising from climate change and natural disasters includes an additional modelling layer that needs serious consideration. Personal experience or expectation of future disasters makes investors and managers care about such events on a purely non-monetary basis. Consequently, the standard investment objective extends beyond a simple maximisation of a portfolio's risk-adjusted return to include nonpecuniary motives related to sustainability. Notably, even in the case in which asset managers do not care themselves about such nonpecuniary motives, as long as the end investor values such attributes, the delegation force, and related penalties associated with the deviation from the investors' objective, can be powerful enough to align managers' and investors' interests. Clearly, the interaction between the two forces may either amplify or dampen the overall effect on investment decisions. Taking this perspective, from a modelling standpoint, an asset manager's utility function should include not only monetary values but also broadly defined ESG factors.[98] An example of such a factor could be firms' contribution to global warming.

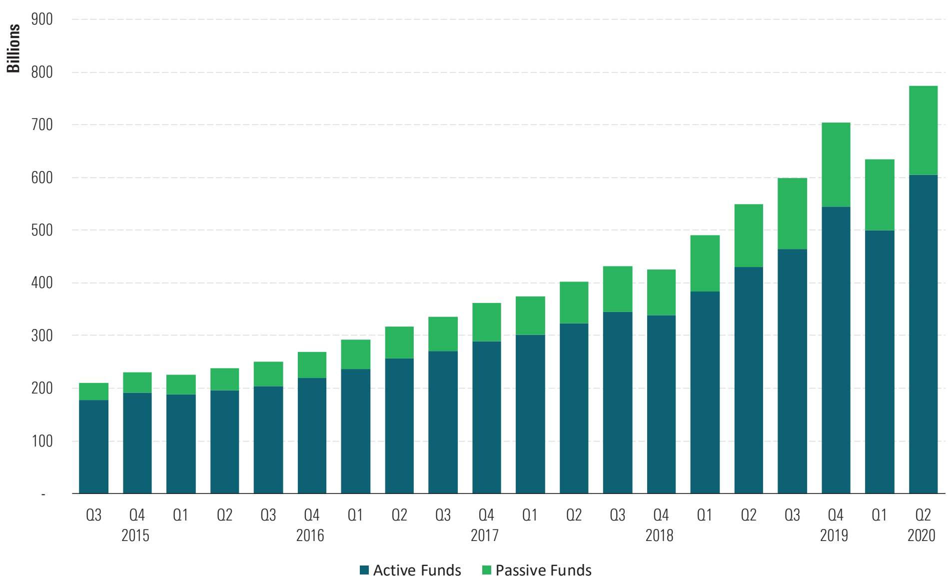
The ESG paradigm is deeply rooted in the stakeholder theory of a firm and has attracted great interest in broader economic circles. On the practical side, the growth in ESG investment is a relatively recent phenomenon and has been particularly strong in times of large negative shocks, such as the global Covid-19 pandemic or the looming climate change crisis, which is consistent with the view that investors pay more attention to social responsibility in times of natural disasters. Notably, this growing attention can be rationalised either by factors which are not measured in monetary terms or by factors that reflect the hedging activity of the disaster risk. In the first case, the worry is that the

98 This perspective has been emphasised for example by Hong and Kacperczyk (2009), Broccardo et al. (2020), and Bolton et al. (2020c).

trend can weaken once investors realise that ESG investments do not produce significant returns. The strong aspect of the second case is that the hedging motives, by their design, rule out the profit motive as a leading principle. On a purely anecdotal level, some of the market developments can be explained by herding motives, some of which could have purely behavioural triggers. In this regard, many practitioners have resorted to the FOMO ('fear of missing out') acronym as part of the explanation behind the market trend.

Irrespective of the reasons, the growth in ESG investments has been impressive. As of 2020, more than $40 trillion worth of assets managed globally have had some form of ESG consideration, with a vast majority being actively managed. This number has doubled over the last four years and more than tripled over the last eight years. Figure 6 illustrates the tremendous growth in assets under management using an example of European sustainable mutual funds. The data show the time-series evolution of quarterly assets under management over the 2015–2020 period.

FIGURE 6 **ASSETS UNDER MANAGEMENT BY ACTIVE AND PASSIVE EUROPEAN SUSTAINABLE FUNDS (€ BILLION)**



Source: Morningstar Direct, Morningstar Research. Data as of June 2020.

The data show a four-fold growth in assets under management, with the largest percentage increases occurring in the last two years. Interestingly, the growth has come both from active and passive fund companies. Globally, as of June 2020, the value of mutual funds strictly following sustainability mandate, as reported by Morningstar, had reached about $1 trillion.

From the perspective of the cross-section of global asset management, the question is whether managers in different countries are similarly exposed to natural disaster shocks. As has been apparent from the climate change discussion, not all countries are equally attuned to the notion of looming risks. Part of the reason could be cross-country differences in political sentiment, which could also be endogenous with respect to social preferences. Such differences in social norms among individuals or investors can drive differently the pressure on the asset managers to adjust. Further, the ability to share risks can differ across regions with different access to financial assets. For example, investors with domestic investment bias may find it easier to shield from risks if their local habitat features assets with high and low exposures to the disaster risks. Similarly, investors from more financially savvy countries may be more willing to share their risks by investing in both developed and emerging markets. The question of interest is to what extent such heterogeneities are reflected in asset prices globally.

The data in Table 1 show that the geographic distribution of sustainable investment is not even. Among broad geographic areas, Europe dominates the investment landscape, with over 80% of all sustainable assets under management, followed by the United States and Asia. In the second quarter of 2020, Europe also received the highest share of aggregate flows, confirming its dominance on the global scene. The dominance of Europe over the United States is particularly surprising given that the asset management sector in the United States is much larger than in Europe.

TABLE 1 **SUSTAINABLE FUNDS IN A GLOBAL PERSPECTIVE: FLOWS, ASSETS AND NUMBER OF FUNDS**

	Q2 2020 flows		Assets		Funds	
	US$ billion	% total	US$ billion	% total	No.	% total
Europe	61.4	86.3	870.3	82.0	2,703	78.8
United States	10.4	14.6	158.9	15.0	315	9.2
Japan	0.0	0.0	4.8	0.4	116	3.4
Australia/New Zealand	0.1	0.2	12.6	1.2	108	3.1
Canada	0.1	0.1	6.5	0.6	91	2.7
Asia ex-Japan	-0.9	-1.3	8.5	0.8	99	2.9
Total	**71.1**		**1,061.5**		**3,432**	

Source: Morningstar Direct, Morningstar Research. Data as of June 2020.

Initial evidence from the work by Bolton and Kacperczyk on global institutional investors suggests that asset managers in Asia and Europe are generally more sensitive to climate-related risks than managers in the United States.[99] This is largely because the climate issues are more salient in those regions, further supported by their political constituencies. Consequently, one would expect the future growth of socially responsible investments to also be faster in these regions. From a competition point of view, this also means that asset managers in those regions are likely to be more constrained in their behaviour than those in the United States. As such, their ability to outperform their global peers may be limited. In a market in which investors do not fully appraise social focus, that heterogeneity may create a disadvantage in attracting flows and growing asset size. While conclusive evidence on this question is still missing, the distribution of asset managers globally and their ability to compete partly depends on the relative weights each country puts on monetary versus non-monetary factors.

Finally, what is also relevant for the subsequent discussion is the inherent heterogeneity in asset managers' investment objectives. Such heterogeneity is crucial to make sense of general equilibrium in this sector. If all asset managers were buying the same green assets, who would be selling them? For that to happen, there has to be either some investors who hold different views about the world (so-called sceptics) or investors who may be agnostic about the situation and simply participate in the markets as natural arbitrageurs. In the process of investing, some of the investors will necessarily gain at the expense of others. Understanding how the two groups may potentially justify their presence in the market is another aspect of the investment paradigm that needs to be discussed. Here, departing from utilities that depend strictly on monetary outcomes may be one way to rationalise the observed changes.

In sum, the world of asset management in the context of natural disasters and climate risk retains many of the typical features of the sector based on the models of delegated portfolio management and asset pricing. However, these theories alone can explain some but not all nuances of the investing paradigm. The rest of this chapter illustrates the specificities of the context by focusing on various aspects of the risk management process.

3.3 BUILDING RESILIENCE TO CLIMATE CHANGE AND NATURAL DISASTERS

Natural disasters and climate change constitute a negative shock systematically affecting social welfare. Given their economic size, they are likely to have a nontrivial impact on the portfolios of asset managers, so the risk of their occurrence needs to be carefully managed. It is therefore vital to design a system that would allow for better resilience of society to such risks. Practically, this means effective risk management that reduces the possibility of large drawdowns in values of assets under management.

99 See Bolton and Kacperczyk (2020d).

The process of risk management follows a sequence of risk characterisation, measurement and management. To the extent that each step in this process could be identified, managing natural disaster risk – apart from the scale issue – would not differ much from how many other risk types are managed. This could mean including elements of risk budgeting or outright insurance purchases. However, the context of risks that are not fully specified, as is the case with climate change risk, presents additional challenges, the most symptomatic ones being the systemic nature of the underlying risks and severe uncertainty underlying the wealth/consumption stochastic process.

The systemic nature of the shocks makes them difficult to hedge because of the limited ability of financial players to share risks. The uncertainty enters risk management in two ways. First, infrequent observability of large shocks, or 'tail events', generates significant estimation error of any stationary system. Second, and more specific to the climate risk application, is the uncertainty resulting from a potential non-stationarity of the underlying wealth-generating process. For climate risk, the dynamic structure of underlying risks and/or irreversibility of physical changes are just two examples of how difficult the portfolio management may become.

The above considerations challenge the risk management process in several ways. First, the unusual nature of climate risk makes the identification of downside risk far from obvious. The changing climate can mean severe damages for some geographic locations and asset types, but it can also mean great opportunities for others.[100] For example, the thaw of permafrost in Northern Eurasia may expand economic frontiers of this region; it may also mean severe droughts and hunger in Southern Europe, on a scale often seen in Africa. Second, the typical measures of risk measurement may suffer in terms of their practical use for asset management. The typically used return volatility has already been problematic in the context of tail events. But even more tail risk-tailored measures, such as value at risk or expected shortfall, may be difficult to measure in the context of nonstationary distributions. While the above aspects of risk management are very important for a well-functioning asset management sector and its hedging activity, the scope of this chapter offers limited ability to devote the necessary attention to either of the two. Hence, the remainder of the chapter strictly concentrates on the third part of the process, which is risk management itself.

The hedging objective

When it comes to risk management, hedging constitutes an important component of welfare-protecting activities undertaken by the private sector, and especially asset management. What is often not fully appreciated is that hedging does not come without costs and requires careful understanding of the objective function the decision maker aims to maximise. In the context of asset management, the traditional role of which

100 An interesting discussion of this point is provided in Hong et al. (2019).

has been to generate abnormal returns, the principle of hedging becomes problematic because of its costly nature that directly takes away from the value creation. This chapter takes the view that resilience-building and mitigation actions in the presence of climate risks should probably take the central spot mostly because the offsetting costs, if applied at the appropriate time, are more short-term than the resulting long-term benefits. Yet, it is important to understand some of the key trade-offs associated with this process, especially because in the short term, the cost component is a major factor in the survival of individual institutions.

Starting with the simplest, entering hedging contracts may involve monetary costs similar to the purchase of a standard insurance policy. Some of the contracts, such as futures or forwards, may be costless at origination, but they still require collateral. Similarly, each contract requires a counterparty and, depending on the situation and the market design, the search for such a party can be costly. Further, even a simple portfolio rebalancing, which is one of the common ways to manage exposure to risks, if launched on a large scale or simultaneously by many players, can generate significant trading costs. More broadly, hedging may also involve significant opportunity costs. In the world of portfolio selection, such opportunity costs could represent a worsening risk-return trade-off resulting from constrained optimisation. Various constraints could range from an inability to take leverage positions, to constraints on the types of investable assets, to a reduction in a portfolio's tracking error.

Unlike other financial players, such as banks or insurance companies, asset managers rarely invest their own money. As such, most of the assets they hold are claims of outside investors in the form of asset shares. In most circumstances, they are also not explicitly covered by government guarantees, which makes them generally more exposed to large shocks. In the absence of these popular risk management tools, the simplest mechanism through which asset managers could mitigate some of their portfolios' risk is by holding some of their assets in cash. By definition, cash equivalents are considered as a close substitute to a risk-free asset due to their liquid nature and ease of conversion to other assets. Also, since cash is the most liquid asset, it meets the objective of satisfying redemptions and rarely leads to selling assets at fire-sale prices. In fact, the idea of holding cash-equivalent assets underlies the principle of investing along the capital allocation line (CAL), one of the cornerstones of the portfolio theory. However, the idea of investing along the CAL is elusive in a world in which asset managers are bound by their style mandates; equity funds are expected to hold a significant proportion of equities, and so are bond funds. Hence, many asset managers are constrained in their ability to hold sufficient amounts of cash. Furthermore, holding cash involves large opportunity costs, and the competitive environment in which managers operate makes it very difficult to hold large cash buffers. For example, US equity mutual funds hold an average of 5–10% of their portfolios in cash-equivalent assets, and many of them hold less. Finally, using cash seems a sensible mitigating tool in a static world, but it is not as obvious if the world of investing is dynamic because of intermediate risks associated with cash replenishment. Consequently, asset managers require different techniques to manage risk than are typical in other contexts.

The most obvious alternative is portfolio diversification, an idea that allows asset-specific risks to be eliminated through pairing them with other relatively uncorrelated risks. That diversification is a simple, yet powerful force could be argued by observing a rise in indexing activity. For example, in the United States more than 50% of institutional money is passively managed. This paradigm of investing is particularly popular among retail investors and those with little investing experience. However, while very easy to implement, diversification does not come without costs. One such commonly discussed cost relates to asset managers' information acquisition process. In a world in which information collection is costly, adding more assets to a portfolio rarely happens without sacrificing the expected return margin. This observation is a result of decreasing returns to scope. The main insight of the idea is limited attention underlying managers' information acquisition. Simply put, active managers can only learn about so many ideas at the same time. Hence, spreading their attention across multiple assets involves the dissipation of information quality. Logically, one should thus expect that informed managers hold more concentrated positions. This insight finds its place among most successful asset managers. As Warren Buffett, one of the most successful managers of all time, put it bluntly, "[d]iversification is only for those who do not know what they are doing". The prediction about the diminishing returns to information gathering finds its formal grounding in the theoretical literature on information economics.[101] Likewise, empirical research on the topic is broadly consistent with the predictions. Empirical research on the topic using a large panel of US mutual funds over the 1980–2005 period shows that US equity mutual funds with more concentrated portfolios outperform portfolios of funds which are more diversified.[102] Similar results also apply to non-US mutual funds as well as other actively managed companies, such as hedge funds. Another cost of diversification results from simple statistical evidence on asset return correlations. It is well known that in the presence of large negative shocks, diversification is unlikely to work well since correlations among asset returns tend to rise in tandem in times of market stress. Finally, natural disasters usually involve large economic damages. In this regard, the demand for hedging assets may create price pressure if the hedge trades are correlated across multiple managers. This force again makes diversification costly. Overall, the process of hedging natural disaster risks using a simple idea of portfolio diversification may be quite complicated.

101 Theoretical predictions of the decreasing returns to information production are presented in Van Nieuwerburgh and Veldkamp (2010) and Kacperczyk et al. (2016), who show theoretically that the intensity of privately informed trading decreases with portfolio diversification.

102 See Kacperczyk et al. (2005).

At the macro level, the question of hedging also involves aggregation of individually hedged portfolios, which may not necessarily maximise the global planner's objective. The discrepancy between the private solution and the planner's problem can create coordination frictions and may additionally add up to the impossibility of fully insuring disaster risk. The failure to design a global carbon tax system is just one example of such coordination costs. Another manifestation thereof was the heterogenous response of different countries to resolutions of the Paris Agreement.

'Doing well by doing good'

The conflicting nature of the hedging principle is well exemplified by the common principle underlying a lot of socially responsible investments, described as 'doing well by doing good'. Under this adage, asset managers should be able to preserve their financial returns by expanding their mandates into creating additional welfare through a menu of non-monetary 'goods'. The main challenge with this paradigm is that constrained optimisation by design is unlikely to beat unconstrained optimisation. In fact, little empirical evidence from the investment world exists that would be robust and economically sizable evidence. If anything, contrary evidence suggests that exclusionary investing is financially costly,[103] even though evidence from the Covid-19 episode indicates the outperformance of socially responsible funds during this period.[104] Still, this is one very special event, and it is not clear whether its external validity carries forward. More importantly, the outperformance of strong ESG stocks in recent times could in fact be consistent with the shift to a new equilibrium whereby strong ESG stocks become highly priced at date zero with the expectation of small returns in the future. Whether recent evidence is actually an example of this transition is hard to tell, but the results are consistent with exactly such a narrative.

More broadly, to rationalise managers' focus on sustainability, one would need to redefine an objective function such that both pecuniary and nonpecuniary motives play a direct role in individuals' or planners' utility. This consideration underlies some of the recent theoretical models.[105] The idea of fitting one global objective may become challenging if constraints are not uniform across agents. For example, pensions, endowments and banks are typically more sensitive to nonpecuniary factors than are hedge funds or independent advisors, as will be shown later in Figure 7. From a risk management perspective, the goal of stabilising flows is quite powerful. As has been shown, asset managers with ESG-tilted portfolios are generally less exposed to negative shocks. Moreover, in the presence of shocks directly correlated with ESG screens, one can imagine that capital may flow in rather than out of such institutions. In this regard, a stabilising role of flows may be a partial offset to return-based effects induced by self-imposed constraints.

103 See, for example, Hong and Kacperczyk (2009) and Bolton and Kacperczyk (2020a).
104 See Pastor and Vorsatz (2020).
105 See, among others, Oehmke and Opp (2020), Pastor et al. (2020) and Pedersen et al. (2020).

Hedging natural disasters and climate risks

Hedging is one of the most natural activities that can mitigate natural disasters and climate risk. To set up an effective hedging system, it is important to separate risk into hedgeable and non-hedgeable components. This distinction matters because hedging each type of risk is very different in the world of financial markets.

Financial markets are typically well suited to hedging non-systemic risks. These can come in two forms: asset-specific (idiosyncratic) risk and systematic but hedgeable risk. One of the simplest ways to hedge such risk is through effective diversification. Asset managers can design portfolios of assets that take advantage of the fact that asset values are not exposed to the same risks at the same time. This property is usually manifested by a low correlation structure among different asset returns. When it comes to natural disasters or climate risk, this principle can hold when the target of the shock is fairly localised. For example, only some geographic regions are negatively affected by negative risk or only some industrial sectors are exposed to such risks. By holding assets that are not exposed to such risks, investors are taking advantage of risk sharing.

In an investing environment in which risks are fully specified and priced, another tool to hedge risks could be derivative contracts. In their hedging role, derivative contracts allow their users to financially engineer payoffs of a desirable form. As a simple example, a buy of a put option could receive a payoff when the asset value drops. In this regard, the contract operates very similarly to a traditional insurance contract. Such contracts can hedge either individual assets' risks or even macro risks, such as market risk. The seller of the insurance contracts is able to pay off the investors by hedging their exposures with countervailing contracts, or by pooling the upfront premiums, as is the case in traditional insurance. What is important in this process is the existence of assets covering all the relevant contingencies – so-called state-contingent claims. In the context of natural disasters and climate risks, catastrophic bonds or weather derivatives are among some of the more popular contracts. Interestingly, despite their relative simplicity and hedging benefits, several types of asset managers – especially mutual funds – do not use derivatives on a large scale, either because they choose different ways to hedge their risks or because they self-impose constraints on their derivatives trading. An alternative reason could be lack of effective hedging instruments. Here, the financial sector could come to the rescue by designing a more comprehensive list of hedging tools.

The situation becomes more problematic if the risks are not fully specified, or if financial markets are not fully complete – that is, some state contingencies cannot be insured. This is a likely scenario for climate-related risks that are dynamic and fairly complex. A simple example of such incompleteness are long-term risks. Because of their uncertain nature, it may be too costly for the protection seller to fully price the risks and hedge them appropriately. Thus, one can only hope for partial solutions. In this spirit, hedging climate risk involves textual analysis[106] or the use of low-carbon indexes.[107] In the former, investors dynamically hedge climate risk using information on innovations in climate change based on news articles. The benefit of this approach is that they can gradually adjust their exposures to climate change even though the risk is inherently long-run. Though in the short run such hedging may be costly, ultimately the long-run gain may offset this. In the latter, an investor exposed to risks associated with stranded assets or high carbon emissions may want to invest in low-carbon portfolios. In fact, such portfolios have become very popular, especially in the post-Paris Agreement era. For example, the value of the most popular carbon ETF has increased its asset size by a factor of five over the last five years. Empirically, the advantages of low-carbon portfolios are desirable tracking error properties and a tendency to offer superior returns in sample. Nonetheless, it is important to note that in the above scenarios, one has access to assets that pay off in cases of negative climate risk – hence, markets are still fairly complete.

The most difficult scenario involves hedging of systemic risks. In the case in which all assets are systemically exposed to climate risk, providing private insurance may not be feasible because risk sharing by private institutions is not possible. One possible solution to insuring such risks would be through the public sector. In a general framework, the system could involve an insurer of last resort that would be willing and able to bear the financial cost, akin to how the lender of last resort functions. A natural counterparty could be a government agency or central bank. To form a parallel, this setup could be very similar to the mortgage system in the United States, where institutions such as Fannie Mae or Freddie Mac insure risks associated with mortgage credit risk. The advantage of using the public sector as an ultimate underwriter of risk is the public sector's ultimate funding ability guaranteed by its control of monetary payments. Moreover, the involvement of the public sector may be incentive-compatible if it actually allows the public entity to boost aggregate welfare. Of course, setting up such an insurance system should still involve a careful cost-benefit analysis taking into consideration moral hazard issues and the fragility of sovereign debt. In sum, in the context of largely non-hedgeable risks, a system that complements the private sector with the engagement of the public sector may allow for better resilience of social welfare.

Short-term versus long-term risks

The second relevant idea involves the resolution of the underlying risks over time. Even though natural disasters are economically large, their impact may materialise over different horizons. On the one hand, climate risks may capture the transition risks involving ongoing changes in renewable energy production or shifts in social norms oriented on climate issues. These effects could be considered short-term risks. On the other hand, climate risks can also involve effects that materialise over medium to long

106 Engle et al. (2020).
107 Andersson et al. (2016).

horizons. For example, climate policies may affect the business environment over the long run. In a similar way, the physical risks of climate change may not be immediately transparent. Given these considerations, it seems natural that asset management would react to such risks with a dual approach of balancing both types of horizons. Yet, what seems common is asset managers' focus on short-term risks. One of the reasons may be the inherent difficulty of predicting long-term effects. Another explanation that is more specific to the asset management industry itself is the agency conflict between managers and investors. Since investors often focus on short-term portfolio returns, they shift asset managers' incentives towards myopic behaviour. In fact, a vast empirical literature has argued that flows to asset management companies are highly sensitive to short-term performance.

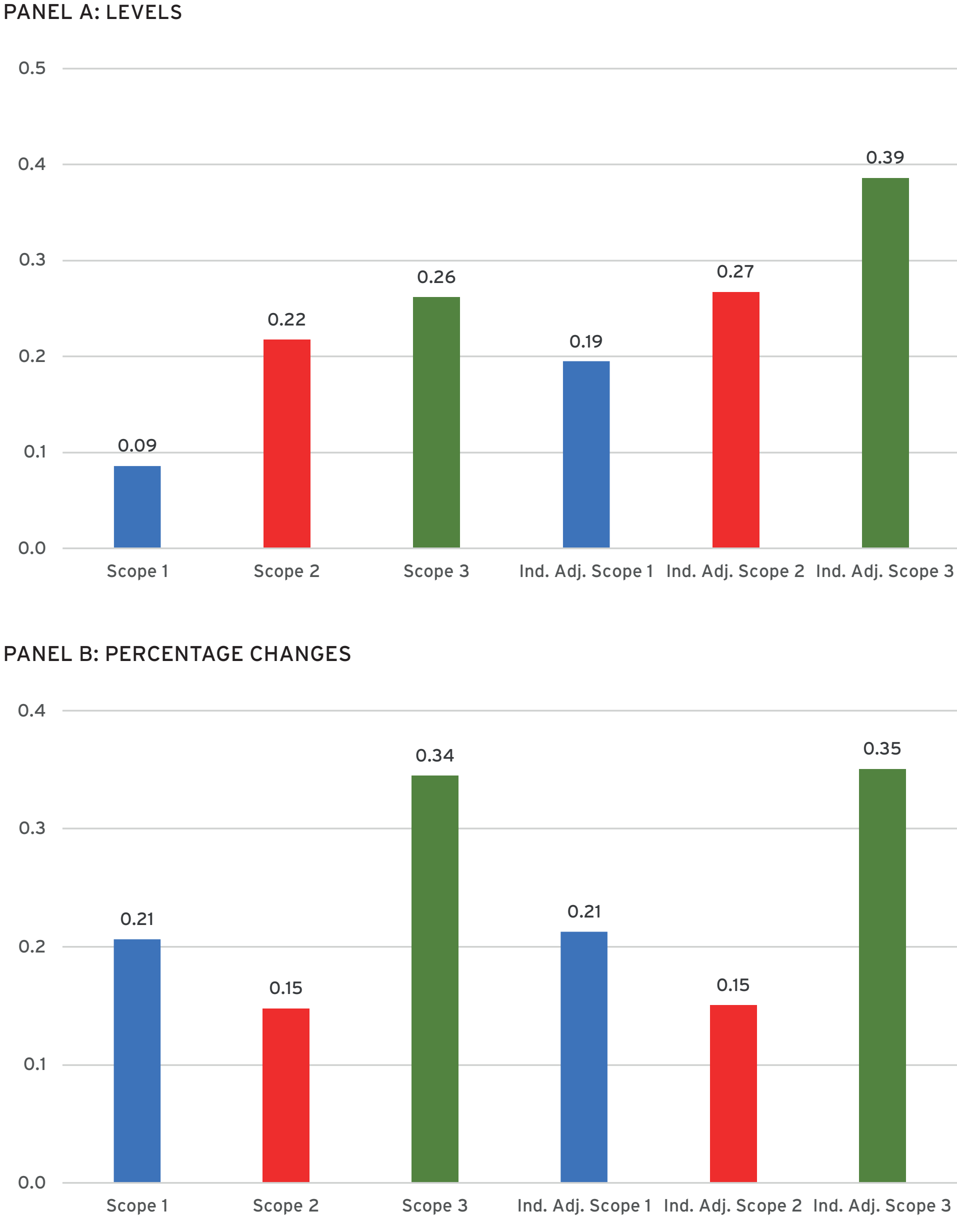
To provide empirical verification of these claims, Bolton and Kacperczyk examine whether investors, in general, care about carbon transition risk.[108] Using a global sample of firms over the period 2005–2018, they show that firms' stock prices reflect both long-term and short-term effects of transition risk. To capture this effect, they estimate a regression model with monthly stock returns as a dependent variable and the two variants of carbon emissions as the main independent variables: natural logarithm of emissions, and percentage change in emissions across three different types of emissions (commonly defined as 'scopes'). Scope 1 captures direct emissions at source; scope 2 relates to emissions from the consumption of purchased electricity, heat, or steam; and scope 3 relates to indirect emissions from the production of purchased materials, product use, waste disposal and outsourced activities.[109]

Figure 7 illustrates the effect based on a sample of more than 14,500 firms representing 77 countries. Return premia based on emission levels (Panel A) and those based on percentage changes in emissions (Panel B) are separately considered. Blue represents scope 1 emissions, red scope 2 emissions, and green scope 3 emissions. Each column represents the difference in stock returns between firms with respective emissions measures that are one standard deviation above the average and firms whose emissions are at the average value. The first three bars do not adjust for differences in emissions across industries, while the last three bars do adjust for such differences.

108 Bolton and Kacperczyk (2020a; 2020b).

109 All regressions include year-month fixed effects and country fixed effects. They also include a host of the following control variables. *LOGSIZE* is the natural logarithm of market capitalization (in $ million); *B/M* is the book value of equity divided by market value of equity; *ROE* is the return on equity; *LEVERAGE* is the book value of leverage defined as the book value of debt divided by the book value of assets; *MOM* is the cumulative stock return over the one-year period; *INVEST/A* is the CAPEX divided by book value of assets; *HHI* is the Herfindahl index of the business segments of a company with weights proportional to revenues; *LOGPPE* is the natural logarithm of plant, property & equipment (in $ million); *VOLAT* is the monthly stock return volatility calculated over the one year period; $MSCI_{i,t}$ is an indicator variable equal to one if a stock *i* is part of MSCI World Index in year *t*, and zero otherwise.

FIGURE 7 **CARBON EMISSIONS MONTHLY RETURN PREMIA**



Source: Bolton and Kacperczyk (2020b).

The results indicate that firms with higher levels of carbon emissions across all three scopes of emissions (the measure of long-term risk) have statistically and economically higher stock returns, on average. Similar patterns are detected for firms with higher percentage changes in carbon emissions (the measure of short-term risk). These results hold for a broad sample of firms across many industries and countries and are consistent with the risk-based explanation of transition risk. They are also economically sizable. As an example, the spreads in returns based on the level of carbon emissions amount to 2–4% per year. The effects based on percentage changes are broadly similar.

The above results call for a broader discussion. One of the most hotly debated questions in investment management is whether climate risk is fairly priced, that is, whether assets values properly reflect their levels of risk. While the results show patterns that are consistent with risk-based explanation of prices, the main challenge is that they do not tell us much about fair pricing or some notion of *asset alphas*. For that, one would need to specify an equilibrium model that could determine fair asset prices. In principle, such a model does not exist and hence any discussion of fair pricing naturally suffers from a joint-hypothesis problem. Specifically, traditional models of asset pricing are clearly not suitable for such an exercise as they impose many unrealistic assumptions on a problem that is inherently deeply nonlinear and additionally involves non-stationarities in the data-generating processes. A more realistic take on the data is one in which we can try to characterise cross-sectional distribution in asset prices as a function of precisely measured objects. In this regard, our results provide a useful description of *asset betas*, that is, sensitivities of asset prices to carbon emissions as a stock characteristic. In the long run, scientific discoveries should go in the direction of distinguishing how much of what we find in the data is due to carbon alpha or carbon beta.

Transitory versus permanent shocks

A fundamental distinction driving the risk management process is related to the nature of shocks: are they transitory or permanent? The distinction can be seen through the comparison of Covid-19 with the climate crisis. The former is considered by many to be a transitory shock, especially now that the idea of a successful rollout of vaccines is quite plausible; a similar panacea is unrealistic in the context of climate risk.

The implications of the difference in shock persistence for asset management strategies can be starkly different. In the context of a transitory shock, the hedging activity could be relatively short-lasting as the cost of hedging could outweigh the benefit of staying on the existing portfolio. One could imagine a separating equilibrium in which only some managers tilt their portfolios away from the underlying risk while others follow a contrarian strategy, thereby acting as natural arbitrageurs. The arbitrage strategy would require at least a partial reversal of firm values to previous fundamentals. In the end, the speed of reversals would determine the ultimate profits of the strategy.

The story becomes quite different if the shock is more permanent in nature. For starters, hedging would likely intensify as the exposure to the shock became more lasting. Here, one would want to separate trading activity that simply reflects investors' changing preferences from trading activity hedging against ex-post damage. From a preference perspective, one would expect increased demand for green assets and thus more pooling in asset managers' strategies. This pooling process would manifest itself through a wide-ranging portfolio rebalancing. With sufficiently large capital flows, one would expect a major repricing of assets with different exposure to the underlying risks. Taking an arbitrageur position could be quite risky if the transition to a green equilibrium were to last longer than arbitrageurs are able support it with their capital. A little taster of this idea could be observed in recent months as the markets have observed a major shift to assets aligned with ESG-type objectives. At the firm level, the carmaker Tesla offers probably one of the most prominent anecdotes. Its price has skyrocketed in just a few months and rationalising this movement without reference to a preference shift would be quite difficult. But the story of repricing is likely a more systematic phenomenon that applies to a number of industries and markets.

From an equilibrium perspective, changing preferences for sustainability imply a transition from a 'brown-type' economy to a 'green-type' one. Interestingly, even though the transition period exhibits a massive upward pricing of green assets, ultimately the steady state would imply lower expected returns. This process could sustain the equilibrium in that investors with a relatively stronger preference for sustainability would lose to the benefit of investors with a stronger preference for pure returns. Again, this simple process illustrates why, from a long-run perspective, 'doing well by doing good' is likely a fallacy.

The story of hedging permanent shocks becomes more grim when expected risks materialise and turn into real-life damage. Here, insuring permanent shocks is well-nigh impossible if the shocks are broadly systematic and, through various externalities, affect most parts of the economy. In this case, even those asset managers engaged in hedging would likely endure losses. Taking a short position as an arbitrageur could be potentially profitable but, in the end, the entire asset management sector would experience distress due to a large depletion in aggregate wealth.

Risk management with noisy measurement

As a final point, a broad idea of risk management under incomplete or noisy information is highlighted. One of the main difficulties in pricing and hedging disaster risk results from limited observability of disasters. This infrequent observability issue underlies in general the entire literature on disaster-risk economics,[110] but it is particularly symptomatic in the context of natural disasters. The main issue is that natural disasters

110 See Barro (2006) for general disaster models and Weitzman (2011) for disaster models related to climate.

are highly unpredictable.[111] Moreover, the issue of predictability is further challenged by the nonstationary nature of such risks. In the context of climate risk, it is conceivable that many negative consequences seem to cumulate with an increased frequency and the arrival of the shocks is close to random.

The literature on the topic began to recognise this issue in the context of finance. A recent example of such theory models the problem within the robust control framework, but the focus there is generally on welfare rather than on micro-founded portfolio decisions and hedging of risk.[112] Clearly, from an asset management perspective, building portfolios with proper adjustments for noisy and nonstationary risk is quite challenging. There is very little theoretical or empirical evidence that informs such a decision. Intuitively, it feels that asset managers should underweight assets with high exposures to the uncertainty risk, but in a competitive framework the decision to refrain from risky assets needs to be evaluated in a quantitative way. Hence, it is likely that asset managers would deviate from the optimal portfolio outcome.

3.4 MITIGATION OF CLIMATE CHANGE AND NATURAL DISASTERS

The discussion so far has emphasised the interplay between asset managers, whose objective is to secure the wealth of their clients, and their investment environment. While the hedging orientation is important, especially in the short and medium horizon, in the long run, if the disaster risks are not contained, hedging activity will likely become less effective. What is also necessary for building successful socioeconomic resilience is a simultaneous mitigation activity aimed at reducing the stress on the entire system. One of the key questions is how to elicit a socially desirable outcome when it comes to managing tail risks. Political actions are powerful but fragile because coordinating mitigating actions is relatively costly. Can institutional investors be used as (partial) substitutes or complements in the battle against crises?

Asset managers are well positioned to take on a leadership role in this regard. Anecdotal evidence is full of examples of managers, such as Larry Fink of Blackrock or Cyrus Taraporevala of State Street Global Advisors, who have already engaged their companies in such mitigation efforts. This section provides a more general perspective on the issue. It begins by contrasting the two most popular approaches to stimulating change. Because of their size and economic importance, large asset managers can have activist and trading (divestment) effects on the corporate sector. The main difference between the two is that activism involves a direct intervention in corporate matters, whereas divestment works indirectly through cost-benefit incentives. Within the activism channel, a more recent channel – carbon emissions disclosure – is singled out. Next, the role of asset managers

111 Although the standard approach to modeling natural disasters assumes that the occur at random times, from the broader perspective of pandemic or climate change, one can argue for some degree of predictability.
112 Barnett et al. (2020a).

as actors that can raise social awareness of climate change risks is examined. Further discussion is on the importance of asset managers in financing mitigation actions by the real sector. Finally, some contracting issues that could incentivise hedging and mitigation efforts are highlighted.

Do asset managers discipline other agents?

One of the most prominent activities asset managers can engage in is corporate activism. Activism is mostly organised around voting campaigns focused either on direct corporate actions or on changes in corporate leadership. Successful activism can lead to the adoption of socially friendly corporate policies. The most prominent of all is likely a reduction in GHG production, or at least a commitment to do so. Activism can also organise minority groups around an important social agenda by providing necessary leadership and/or resources. Moreover, activists may launch campaigns to oust irresponsible directors. While some engagement activities may be organised by individual managers, the most successful ones are often organised in groups supported by policymakers.

One specific instance where activism has proved particularly helpful is in forcing the disclosure of climate-related information. As an example, institutional investors demand from companies a direct disclosure of their carbon emissions, with a view to pricing the underlying risks better. This effort becomes especially relevant, in the absence of high-quality data, for assessing the costs and benefits of firms' transition to a green equilibrium. Environmental shareholder activism increases the voluntary disclosure of climate change risks, especially if initiated by institutional investors, and even more so if initiated by long-term institutional investors.[113] Even though institutional investors are a significant intermediary through which information disclosure is enforced and monitored, over the last few years it has primarily been stipulated by policymakers, who have intensified their efforts to promote disclosure of such information. This policy involvement has been signified by two initiatives. The Paris Agreement adopted a resolution to broaden the scope of climate-related information, taking a particular note of indirect scope 3 emissions. Another prominent initiative is the Taskforce on Climate-Related Financial Disclosures (TCFD) of 2017, which stipulates firms' commitment to disclose their carbon emissions and other climate-relevant information. The main underpinning of the success of this initiative is its global reach, further reinforced by the support of prominent policymakers including Janet Yellen and Mark Carney.

While the disclosure efforts have triggered a visible shift in voluntary disclosure by several companies, the question is whether such information matters for asset managers and whether it in fact leads to a subsequent reduction in emissions. Some sceptics say that such disclosures do not include useful information. For example, a recent survey of 2,000 investors conducted by HSBC found that just 10% viewed the disclosures as a relevant

113 Flammer et al. (2020).

source of information. At the same time, many prominent figures express strong support for mandatory disclosure. For example, in February 2020, Hiro Mizuno, Executive Managing Director and CIO of the Japan Government Pension and Investment Fund, said: "It is necessary for all parties in our investment chain, from portfolio companies to asset managers, to support TCFD so that asset owners like us can properly assess our portfolio. I am convinced that disclosure will continue to evolve as a major framework for such disclosure and strongly recommend all corporates to join." Hence, it seems empirically relevant to assess the importance of disclosure on portfolio decisions and the cost of capital.

In their recent work, Bolton and Kacperczyk evaluate the response of fund managers to newly disclosed scope 1 firm-level carbon emissions information.[114] Using a sample of global firms and institutional investors over the period 2005–2018, they compare the institutional divestment of firms that switch to direct reporting of carbon with the divestment of firms with identical levels (or identical annual percentage changes) of scope 1 emissions that are not directly disclosed. The analysis is based on a regression analysis in which firm-level institutional ownership is a left-hand side variable and the main right-hand-side variable is the interaction term between measures of scope 1 emissions and an indicator variable, Disclosure, equal to one if a firm directly discloses its scope 1 emissions and zero if the information is imputed by the data provider, which in our context is Trucost. The regression model accounts for additional confounders by including various firm-level controls as well as a host of fixed effects that absorb unobservable characteristics that are not time varying. Figure 8 reports the results from the estimation by showing the incremental effect of disclosing information for firms with otherwise similar fundamentals measured by the level or changes in scope 1 emissions.

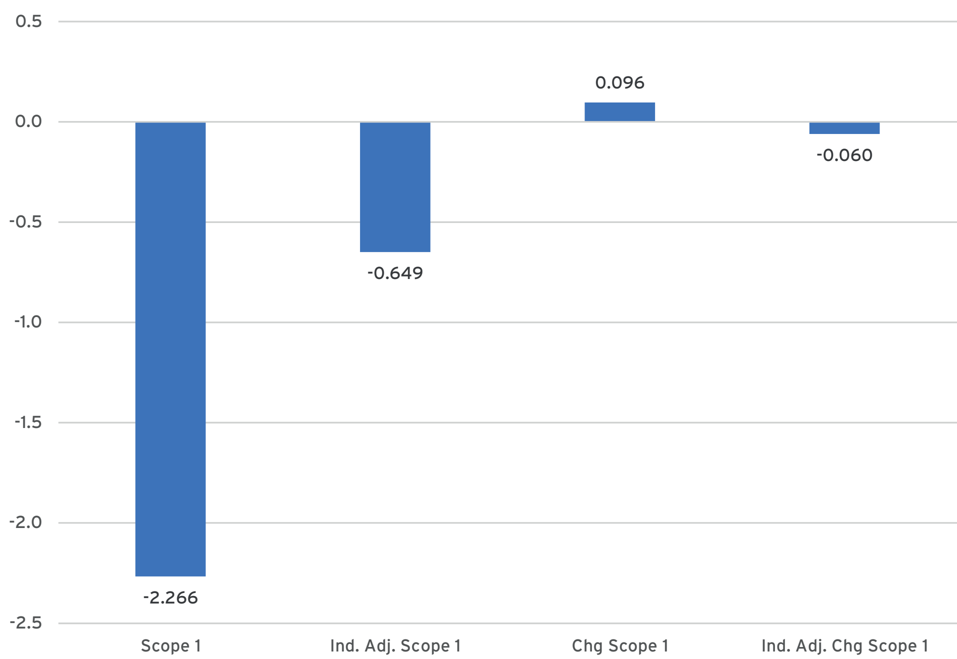
The main result of the analysis is that, upon disclosure events, asset managers tend to divest of companies based on their levels of emissions, but not on changes in emissions. For example, companies with similar fundamentals and the same level of scope 1 emissions have 2.3 percentage points lower institutional ownership if they directly disclose their emissions than if their emissions are estimated by the data provider. The result is 65 basis point lower ownership if one also accounts for the fact that the two companies also share the same industry. The same set of results shows almost no differences if emissions are measured in terms of annual percentage changes.

At first, this divestment result seems counterintuitive given that disclosure should lead to a reduction in uncertainty about firm-level risks. However, one could rationalise the finding in at least two ways. First, investors may be ex-ante more optimistic about companies' true emission levels and may be negatively surprised by the revelation of true information. Second, in the context of companies that directly screen their portfolios based on emissions, disclosure provides a formal certification of the emission levels that

114 Bolton and Kacperczyk (2020c).

often interacts with the firms' mandate to shun polluting firms. The former explanation seems less likely in the context of our empirical tests as we show that levels of emissions do not change markedly around the disclosure events. A separate point is whether such disclosure-driven divestment is a likely trigger of a change in a voluntary disclosure policy. Evidence suggests the opposite. To the extent that divestment is generally known to increase cost of equity,[115] it seems that firms may be less likely to disclose their information voluntarily. As a result, mandatory disclosure policies may be necessary if greater disclosure is the planner's objective. Some evidence on the consequences of mandatory carbon emission disclosure comes from the UK market, where in 2013 the regulator imposed the requirement of scope 1 and scope 2 emissions on publicly listed companies. The result of this activity has been a reduction in average firm-level uncertainty. Interestingly, the change has also made firms in other connected countries more likely to disclose their emissions.[116]

FIGURE 8 **CARBON EMISSIONS DISCLOSURE AND INSTITUTIONAL OWNERSHIP**



Source: Bolton and Kacperczyk (2020c).

Overall, the combined evidence on climate-related activism suggests a fruitful path to instil change going forward. At the same time, sceptics maintain that voting in favour of socially beneficial actions does not always translate into real change, which puts into question the true motivations of such behaviour in the first place. Going forward,

115 Merton (1987); Hong and Kacperczyk (2009).
116 Detailed evidence of these effects is presented in Bolton and Kacperczyk (2020c).

one could imagine more accountability by major asset managers for how they follow through on their promises. In a similar fashion, some critics have argued that even though institutional investors may express their interest in facilitating positive change, their intentions are often quite different from their actions. In particular, some proxy voting by institutional investors may not lead to real change or, even more dramatically, the voting decisions themselves may deviate from the stated objective. In this regard, a natural policy action would be more disclosure of both voting decisions as well as the actions resulting from such decisions by large institutional investors at least, since these are the most relevant players for the change to take place.

Institutional divestment based on firm-level carbon emissions

A parallel activity that may trigger change in corporate behaviour is direct trading by asset managers. A large literature postulates that 'voting with their feet' by institutional investors can trigger corporate change, including the promotion of socially friendly policies. In the context of climate change, a direct action would be divesting of assets with a high carbon footprint. Interestingly, the mere process of divesting of high-emission assets need not to lead to a better environment. Even if institutions were to lower the carbon footprint of their portfolios, someone else would be a buyer and the total level of carbon exposure in the economy would not change. What is essential to make a practical difference is that the emitters adapt by reducing their emissions. A sensible question to ask is whether it matters who divests of the assets. One could argue that institutions may have more leverage in this aspect than dispersed retail investors because their portfolios are generally larger, and one decision can have a stronger economic consequence. From that perspective, high concentration in the asset management sector may in fact be beneficial if institutional players support the goal of reducing emissions. One good example of such practice would be Blackrock, a large institution with market impact and a strong preference for a green economy.

From a slightly more micro perspective, the mechanism to put pressure on the corporate sector could also involve some price effects, such as an increase in firms' cost of capital. Given that cost of capital is one of the main determinants of firms' investments and profitability, one can expect firms to internalise such divestment forces in their corporate policies. Theoretical research has presented variants of such a mechanism in the context of social responsibility.[117] One of the first empirical implementations of the pricing effects of such divestment was documented in the context of 'sin stocks' – that is, stocks from the tobacco, alcohol, and gaming industries.[118]

117 Heinkel et al. (2001).
118 Hong and Kacperczyk (2009).

A different perspective on the role of reduced asset prices in stimulating change comes from the context of the discussion of a carbon tax. While proponents of such a tax consider this option to be the best solution from a social welfare perspective, the reality is that a global tax is difficult to implement due to various coordination costs. In this regard, one can consider price effects as an alternative version of a tax system working through the market. While the pricing of climate change may not always be efficient and thus can produce some welfare distortions, a clear benefit is that it is not subject to the same implementation costs as a policy-driven tax. Recent empirical evidence on the positive relationship between carbon emissions and stock returns gives support to this option as a possible alternative.[119]

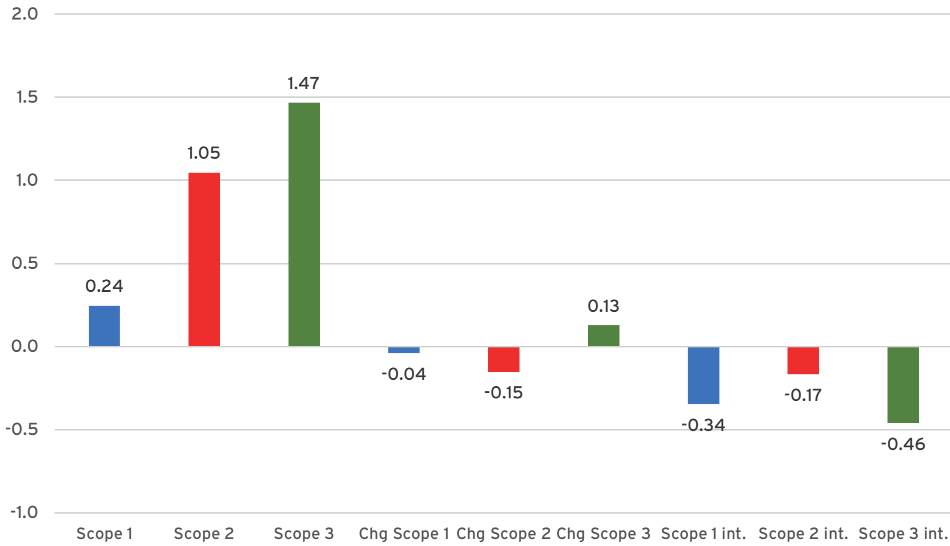
The empirical results below show the divestment mechanism using the setting of carbon emissions. Following the earlier discussion on short-term and long-term measures of transition risk and the fact that such risks are largely priced in, the relevant question is whether asset managers adjust their portfolios using such risk metrics. To answer this question, Bolton and Kacperczyk examine the relation between firm-level institutional ownership and the measures of carbon emissions.[120] Their sample period is 2005–2018. Specifically, the regression model is estimated in which the dependent variable is firm-level institutional ownership, and the main independent variables are firm-level scope 1, scope 2, and scope 3 emissions. The regressions also include common firm-level controls. Finally, the regressions account for underlying differences across countries, industries and time. In this regard, comparisons are among firms in the same industry in a given time period.

Figure 9 shows the results for the estimation based on the same sample as that for risk premia. Measures capturing emission levels, percentage changes in emissions and emissions intensity are considered separately. Blue represents scope 1 emissions, red scope 2 emissions, and green scope 3 emissions. Each column represents the difference in institutional ownership between firms with respective emissions that are one standard deviation above the average and firms whose emissions are at the average value.

Somewhat surprisingly, asset managers do not divest in a meaningful way of the companies that, from a carbon emissions perspective, are riskier. Notably, asset managers, on average, divest stocks based on their emission intensity. However, emissions intensity is arguably not the best measure to capture the transition risk of going towards a low-carbon equilibrium, since lowering the intensity does not necessarily imply lowering the levels of emissions.

119 See Bolton and Kacperczyk (2020a; 2020b).
120 See Bolton and Kacperczyk (2020d).

FIGURE 9 **CARBON EMISSIONS AND AGGREGATE INSTITUTIONAL OWNERSHIP**



Source: Bolton and Kacperczyk (2020d).

The robustness of this result is further explored for subgroups of investors, under the hypothesis that not all institutional types are subjected to the same divestment pressures. Following the standard categorisation of institutions by Factset, a separate look at banks, insurance companies, investment companies, advisers, pensions and hedge funds is performed. The estimation involves the same regression model as in Figure 9, but this time separately for each institution type so that one can characterise potential differences across institutional divestment decisions. As before, all three measures of emissions are considered (levels, percentage changes, and intensities). Figure 10 presents the results, separately for scope 1 (blue bars) and scope 3 (green bars) emissions. Panel A presents the results based on level of emissions, Panel B based on the percentage changes in emissions, and Panel C based on emissions intensities.

FIGURE 10 **CARBON EMISSIONS AND INSTITUTIONAL OWNERSHIP BY INVESTMENT TYPES**

Source: Bolton and Kacperczyk (2020d).

Results show that the unconditional results uncovered before are broadly consistent for each individual subgroup, in that none of the individual groups divests companies based on their emission levels or percentage changes. A more nuanced story emerges, however, for divestment based on emissions intensity. Divestment based on intensity is strongest among investment companies, advisers and pensions. Conditional on any divestment taking place, this result is not surprising because these three types of institutions are typically regarded as being more subject to pressure from outside investors.[121] Perhaps a somewhat surprising result is the weak effect for insurance companies, which tend to behave prudently in their investment choices. Further, divestment is stronger based on firms' scope 1 emissions, which supports the view that such information is more salient and easier to verify.

The above findings offer broad policy implications. Given that the transition risk and the overall agenda of combatting climate change requires a significant reduction in carbon emissions, most likely to zero, it seems natural that for financial institutions to have a meaningful impact on the process, the divestment decision should be based precisely on metrics that capture this specific goal. While emissions intensity has some economic value, it feels that it leaves open the possibility of failing in this task. In contrast, measures of total emissions, as a long-term target, or percentage changes in emissions, as an intermediary step, are more suited to accomplish the objective.

Asset managers and social awareness

Apart from the traditional pricing channels, an alternative role for asset managers can come through their leadership role in driving social norms. In particular, trading can allow investors to express their ideology. If such managers are influential figures, as in the case of Larry Fink, their lead can inspire additional change in other market participants. Empirical evidence suggests that some managers do indeed express their views through their portfolio holdings. For example, fund managers who donate money to the Democratic Party are less likely to hold 'sin stocks' in their portfolios than managers who support the Republican Party.[122] Given the political focus of each party, such behaviour demonstrates revealed preferences of the asset managers. More directly, Democrat-supporting managers are more likely to manage socially responsible funds. From a different perspective, recent academic work discusses the notion of investors' ideology by focusing on non-price factors in the context of wealthy investors.[123] Going forward, one would like to test whether such distinct ideologies can be linked to real changes in social beliefs and corporate behaviour.

121 See, for example, Hong and Kacperczyk (2009).
122 Hong and Kostovetsky (2012).
123 Bolton et al. (2020c).

Given the different disciplinary approaches, a natural question concerns their relative merits, and whether one model dominates the other. Answering this question may be particularly relevant for efficient policymaking and the potential cost-benefit analysis of asset managers themselves. An interesting perspective on this question comes from a recent theoretical study in which social welfare is generated by the two above activities.[124] The study argues that the divestment process may be an inefficient way to trigger change relative to activism. In particular, individual incentives to join an exit strategy are not necessarily aligned with social incentives, whereas they are when well-diversified investors are allowed to express their voice.

Asset managers as financing intermediaries

One of the key prerequisites for society to transition to a better and more resilient world is the involvement of the corporate and public sectors in a transition to clean technologies. Even if the economic system could provide proper incentives to inspire such change, the process would stall if the players were short of capital to finance their investments in resilience. Reliance on external financing is a reality of many corporations and state agencies. Financing constraints can hamper investments and ultimately growth. Hence, it is essential that such financing is provided in a relatively cheap and efficient way. Asset managers are a crucial element connecting capital providers with investors in environmentally friendly ('green') projects. Since they have a superior ability to attract large amounts of outside capital, they can benefit projects with great resource intensity. Moreover, through their expertise, they can provide additional screening and certification of projects subject to adverse selection concerns. This basic intermediation process can be analysed in terms of both supply and demand forces.

From the asset supply side, asset managers can purchase financial instruments whose proceeds are meant to support green initiatives. The most popular asset class through which the intermediation occurs are green bonds, the supply of which has grown rapidly over the last couple of years. Research from the Global Center on Adaptation (GCA), the Climate Bond Initiative (CBI) and the European Bank for Reconstruction and Development (EBRD) finds that more than 5,900 green bonds that have been issued to date include climate resilience components. This number represented more than 920 issuers. On a value basis, by 2020 more than $1 trillion worth of green bonds had been issued, with over $250 billion of this issued in 2019 alone.[125] The United States, China, and France are the leading nations in terms of issuance levels since 2007, while in terms of individual names, Fannie Mae, KfW and the Dutch State Treasury were the three largest issuers in 2019, with each of them exceeding $5 billion in issue value. Interestingly,

124 Broccardo et al. (2020).
125 See Climate Bonds Initiative (2020).

green bonds have also played a major role in the recent pandemic recovery funding. For example, European Commission President Ursula Von der Leyen announced in September 2020 that 30% of the bloc's €750 billion coronavirus recovery package would be raised via green bonds.

Second, private equity firms can engage directly in the development and financing of socially friendly technologies. In this process, asset managers purchase real assets and often contribute to improvements in underlying projects. A prominent example here is the financing of solar energy through private equity investments. Finally, asset managers can also reduce risk for other market participants, thereby reducing financial costs, by providing screening and monitoring, reputational support or liquidity. In support of reputation-based activity, empirical work finds a stronger positive investor response to announcements of green bond issuance when the bonds are certified by a third party.[126]

From the asset demand side, different types of managers accommodate different spaces on the financing spectrum. In the context of green bond financing, bond funds and hybrid ESG funds seem the most natural counterparties. Insurance companies, especially from Europe and Japan, are also active buyers. In general, the demand in green bond markets far exceeds their supply – yet more evidence of investors' increased preference for ESG initiatives. When it comes to real investments, venture capital and private equity companies are the primary capital providers. Finally, for financing of broadly defined ESG initiatives, one should single out the unique role of endowments and pension companies in this process. For example, many prominent university endowments, including the largest ones at Harvard and Yale, openly declare their commitments to net neutrality – that is, supporting the economy with zero carbon emissions after taking into consideration natural GHG capture, such as oceans, forests, permafrost, and so on. Similarly, large pension companies, including CalPERS, openly support green initiatives.

Contracts to facilitate mitigation response

Beyond the general labour-related issues, the question is whether resilience in the context of natural disasters can be achieved through properly specified individual contracts. In the traditional asset management world, most managers are compensated based on their ex-post performance. Managerial contracts can take different forms depending on the specific application, but outcomes are measured mostly on the return scale. In addition, given the delegation feature, the majority of managers are evaluated with respect to their short-term performance. Both features are known to lead to various agency issues within fund companies and may not be consistent with long-term objectives.

126 Flammer (2020).

In a world of natural disasters there may be a need to promote social objectives, and the appropriate metric of comparison may be different from a return-based one. As a result, contracts may need to be redefined so that managers exert effort with a long-term view or an orientation towards nonpecuniary factors. In a market context this can happen in two ways. Organically, the shift in investors' beliefs towards social values may lead to greater rewards for maximisation of social values. In the empirical literature, symptoms of such a shift have manifested in lower volatility of fund flows of socially responsible funds.[127] If outside flows reward more longer-term value, managers will be more likely to gravitate towards such objectives. More directly, one can imagine contracts that directly reward managers for actions that are consistent with maximising the resilience of the economic and global system. An example of such a behaviour, though still not widespread, are Japanese Government Pension Investment Funds (GPIFs). While this type of contract may be the ultimate goal, the challenge is that non-monetary outcomes are more difficult to observe and verify; hence, one can imagine that incentives may not be as powerful as they are in the context of monetary outcomes. Further, a more difficult problem is that of compensation. In a traditional framework, compensation comes directly from the wealth created inside the asset management company. How one should think about monetary rewards of managers who significantly underperform but maximise the social objective is less clear.

A related issue is that of a benchmark specification. This is particularly important in the presence of new investment strategies that are supposed to generate long-term financial success. It is quite natural for fund investors to assess their funds' performance relative to a passive benchmark, or for fund managers to report their performance in such a way. The idea of benchmarking has attracted a lot of interest in recent literature on the topic, both theoretically and empirically, and for conciseness we do not review this literature here. But our question of interest relates to specifying benchmarks specific to ESG-type considerations. A few important observations are noted. First, applying common benchmarks to all ESG managers is generally a bad idea, mostly because the risks and styles associated with this type of investment are quite diverse. Consequently, one would wish to apply more tailor-made adjustments, which is generally difficult in the absence of pre-defined benchmark portfolios. A different idea is to start with the policy objective, such as carbon net neutrality in the future, and build the benchmark around this constraint. This idea underlies the recent move to models that track the relationship between the average level of emissions and the growth in the temperature globally.

A broader concern underlying the shift in fund managers' contracting environment is that the new paradigm may lead to perverse incentives, inspired for example by moral hazard considerations. There are various ways this process can be observed. First, the cost of imposing constraints on managers' actions may lead to risk-shifting and taking uncompensated risks, similar to the 'reaching for yield' that has been observed in the asset

127 See, for example, Bollen (2007) and Hartzmark and Sussman (2019).

management sector. In the absence of a mechanism controlling for such excessive risk taking, one can imagine instability in the asset management sector that could become systemic. Second, fund managers may only pretend to focus on social values by following portfolio strategies that do not translate into real changes. These actions have been coined in the literature as 'greenwashing'. At times, such actions can mask hidden profit motives. An example of such behaviour could be divestment based on carbon intensity metrics. While lower intensity is supposed to coincide with the goal of emissions reduction, it can be achieved without necessarily decreasing total emissions if a company records an even greater increase in sales. Based on this simple observation, some companies have been criticised for setting intensity-based commitments. A recent example of such behaviour was the announcement by Exxon Mobil, which specified its commitment in terms of intensity metrics. Critics argued that, in practice, this commitment meant an increase in carbon emissions levels.

The story above is not an isolated case; the idea of screening based on emissions intensity is prevalent in the entire asset management sector. Research shows that asset managers tend to follow exactly that metric and, in turn, do not follow more direct measures such as levels of emissions or changes in emissions.[128] Another example of potential profit-masking behaviour is related to local bias. Bolton and Kacperczyk study firms' divestment decisions of institutions conditional on their location domicile.[129] In particular, institutional ownership of firms is related to the location of their investors, and the authors ask whether institutions' location matters for different patterns of divestment of firms based on their carbon emissions intensities.

Specifically, using a global sample of firms over the period 2005–2018, they estimate a regression model with firm-level institutional ownership as a dependent variable and scope 1 and scope 3 firm-level emissions intensity as the main independent variable. Results are reported in Figure 11. The illustrated effect is expressed as a change of ownership in response to an economically significant increase in emission intensity.[130] Panel A shows the divestment regression results for domestic institutions, while Panel B shows the results for foreign institutions.

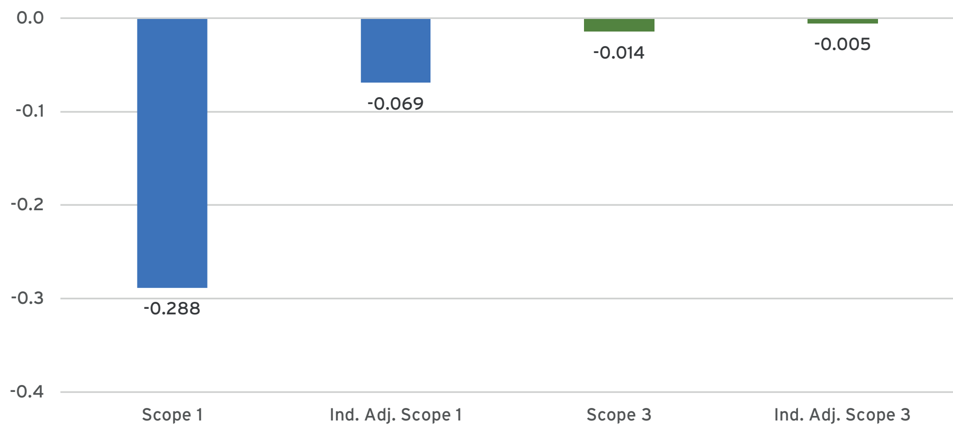
The results show that among companies with the same level of carbon emissions, fund managers are more likely to divest those companies that are not local to them, controlling for many other company attributes including stock returns and profitability. For example, foreign companies are shunned twice as much by their institutional owners relative to similar domestic companies with the same scope 1 emissions intensity (a 0.58% reduction versus a 0.29% reduction in institutional ownership per one standard

128 Bolton and Kacperczyk (2020a).
129 Bolton and Kacperczyk (2020d).
130 Our measure of change is equal to a one standard deviation increase in respective emissions corresponding to the unconditional distribution function of the emission measure.

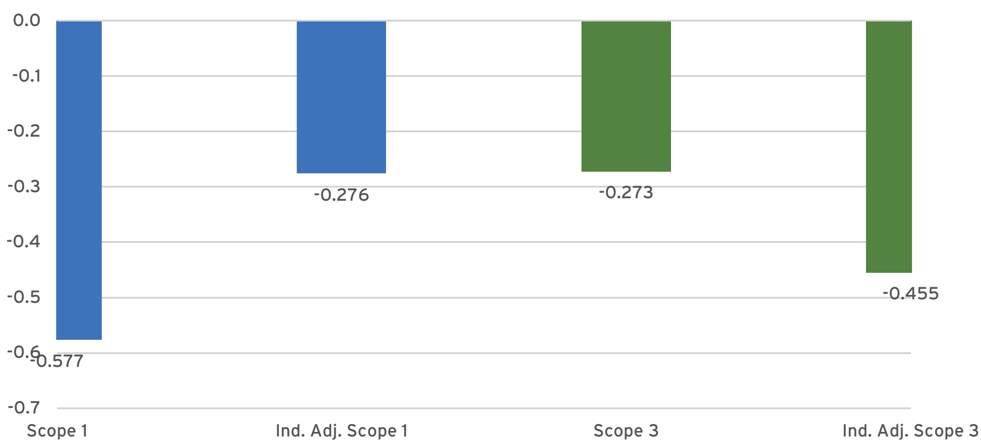
deviation change). The relative differences are even more stark when we focus on scope 3 emissions. These results suggest a hidden motive to promote local firms, perhaps in the interest of maintaining business ties with such companies, which is more likely the case for such asset managers.

FIGURE 11 **CARBON EMISSIONS AND INSTITUTIONAL OWNERSHIP BY INVESTORS' DOMICILE**

PANEL A: DOMESTIC INSTITUTIONS



PANEL B: FOREIGN INSTITUTIONS



Source: Bolton and Kacperczyk (2020d).

Do asset managers care about the underlying disaster risks?

To summarise our discussion in this section, it is useful to revisit current evidence on the question of whether asset managers internalise natural disaster shocks in a way that can provide resilience and stability to the economic system and the social environment. Some of the results discussed so far show that the answer, at least to some extent, is affirmative. Prior work on carbon pricing shows that carbon risk is priced in global equity markets in a fairly efficient way.[131] At the same time, the same studies argue that the pricing effects may not be driven primarily by the portfolio decisions of institutional asset managers. Of course, this does not necessarily mean that asset managers are oblivious to the looming risks. Recent evidence from a survey study suggests that institutional investors already believe that carbon risk is materialising.[132] A more interesting follow-up question is whether they actually take actions consistent with this risk. From a slightly different angle, some research suggests that fund managers overreact to climate risk,[133] while another study shows that investors underreact to climate-related news.[134] This could partly be attributed to a significant measurement error component. Our view is that the asset management sector is clearly waking up to climate-related issues. The question is whether the response will lead to more built-in resilience or to potential instability resulting from improper hedging of such risks or misaligned incentives.

3.5 IMPLICATIONS FOR EFFICIENCY AND WELFARE

In this section, the broad implications for market efficiency and welfare are discussed that result from the hedging and mitigation actions. The focus is on two aspects of welfare: the role of growth in the ESG industry for entry and exit in this sphere, and informational market efficiency and its response to the changing resilience building paradigm.

Implications of ESG growth for industrial organisation

Natural disasters also matter for the broader industrial organisation of the entire asset management sector. As alluded to before, one of the consequences of changing preferences regarding ESG factors is a rise in broadly defined ESG investments. The transition to a new model of managing assets may happen in two ways. Existing asset managers may change their mandates and portfolios towards such preferences, or one may observe adjustments at the extensive margin through entry and exit of asset managers. At present, the former force is likely a dominant mechanism for change in global asset management, but without a well-defined equilibrium it is difficult to say what the steady state should be. Intuitively, if the shift towards a more resilient equilibrium continues, one can expect significant pressure on non-compliers through the flow adjustment mechanism. One can

131 Bolton and Kacperczyk (2020a; 2020b).
132 Krueger et al. (2020).
133 Alok et al. (2020).
134 This evidence comes from a cross-country study of the food industry by Hong et al. (2019).

imagine three types of responses as a result. First, more and more companies may shift towards ESG considerations. Second, non-compliers may exit the market. Third, non-compliers may shift risk in the hope of generating higher returns on their portfolios. The last outcome is particularly interesting in the context of the stability of the entire asset management sector.

In addition to the pure portfolio management function, natural disasters may shape a broader functioning of asset managers as organisations. Some relevant dimensions here include their role in the allocation of capital, risk sharing, labour markets and operational risk. The general shift of asset management towards passive investments has important implications for the allocation of capital in the economy. To the extent that the price discovery function of asset management is reduced, the consequence would be less efficiency in the allocation of capital.[135] From a risk-sharing perspective, an investment world structured around the divestment principle may lead to reduced risk sharing. This has been documented previously in the context of attention stories[136] or exclusionary screening in the 'sin industry'.[137]

In terms of labour consequences, the shake-out of the asset management business and portfolio focus may trigger a major displacement of workers. This can mean the firing of managers specialised in sectors other than ESG. Alternatively, new jobs may be created through the supply of new products catering to ESG. At the intensive margin, one can imagine the repricing of managerial skills either through changes in direct compensation contracts or through expansion or downsizing of asset management companies. Finally, even though in the steady state one could imagine a sorting mechanism whereby managers with certain social beliefs select into ESG-type funds, in the short term there is the possibility of a mismatch between the skill supply and demand created by ESG. All those aspects underlie an enhanced labour risk for professional asset managers and support staff.

Implications for informational efficiency

A final point concerns the consequences of the observed changes in the asset management sector and the growing attention to resilience and sustainability for informational content of asset prices and social welfare. As argued in Section 3.3, the focus on social factors leads to different trading activity of assets with high versus low exposures to such factors. Assets with greater positive exposure should experience more buying and thus higher prices, while assets with small or negative exposure should experience more selling and thus lower prices. However, the simple portfolio rebalancing story does not guarantee that individual asset prices reveal information to market participants, or that financial markets as a whole are informationally more efficient. In particular, if capital choices are

135 More discussion of this issue is presented in Kacperczyk et al. (2020) from a theory perspective, and in Kacperczyk et al. (2021) from an empirical perspective.
136 The canonical presentation of this argument is Merton (1987).
137 See Hong and Kacperczyk (2009).

not driven by information, it is conceivable that adhering to social principles may lead to more noisy prices. A consideration of information efficiency is important in any welfare discussion. As has been argued since Hayek (1945), the efficient allocation of capital is one of the backbones of economic growth and of social development more generally.

In a traditional framework, one would postulate the presence of natural arbitrageurs bringing asset values to their fundamentals. However, in the context of a transition to a new equilibrium, such arbitrageurs may be priced out or limits to arbitrage may constrain their trading activity. If their actions are constrained by, say, limited capital, one may envision an equilibrium in which information will not enter into asset values in an efficient way. As a result, markets may not reflect all the relevant information efficiently. An alternative source of inefficiency could be the growing importance of passive investors. Given that a large share of the asset management sector tends to offer passive ESG products, a consequence could be the reduction in the informativeness of prices. Recent theoretical work shows the equilibrium implications of a growing passive sector and its role in reducing price informativeness.[138] There are two channels underlying this result. First, passive investors, by definition, are not engaged in information production. Second, the growth in their market share, by market clearing, implies less presence of active investors, and thus an additional loss of information-gathering activity. In support of this theory, empirical evidence shows that active institutional investors (both local and foreign) improve the informativeness of stock prices globally, while passive investors tend to make it worse.[139]

Overall, the above evidence may suggest that the ESG movement necessarily implies a social loss. This interpretation is only valid if one specifies welfare in a narrow sense, focusing mostly on consumption and economic output. If one takes a broader view, however, it is no longer clear that the loss on the economic front will necessarily make society worse off. In fact, aggregate welfare may be enhanced if enough people are willing to sacrifice some of their economic wealth for non-pecuniary benefits. This last statement is likely a function of the distribution of ESG beliefs in society.

3.6 CONCLUSIONS

The traditional framework of asset management puts much emphasis on the management of short-term risks. The last decade has observed a major shift in this paradigm, largely sparked by unusual disaster-type events such as global financial crisis, the Covid-19 pandemic and the looming climate crisis. Empirically, we have been witnessing a lot of interest in thinking beyond short-term value, focusing instead on long-term sustainability and resiliency. To many observers, this process seems like the real thing and the hope is that it will trigger a transition to a more sustainable and socially friendly

138 Kacperczyk et al. (2020).
139 Kacperczyk et al. (2021).

world. On the other hand, sceptics would argue that this is yet another cyclical movement in social norms and that the observed behaviour may be short-lasting and more reflective of economic agents' incentives to follow currently prevailing norms. Thus, the question many have been asking is whether the new paradigm is a real game changer or whether it is simply a fad. In this chapter we are relatively far from having been able to answer this question conclusively, as it is really for the future to tell. However, judging by the size of the economic reaction from a wide range of stakeholders worldwide, one could argue that this time may be different. The asset management sector is clearly one of the major players in this process and in many ways a great barometer to assess the sustainability of the process. Since managers' portfolios aggregate information and beliefs in a fast and fairly transparent way, one can use this sector as a litmus test for the efficacy of the underlying transition.

One of the key questions pertaining to 'green swans' – events heralding the climate disaster – is the degree to which the sector can shield itself from their arrival. As this chapter has argued, one of the main challenges is that standard risk management methods, such as diversification or hedging through derivatives, are not disaster-proof. They either do not mitigate risks on a large scale or do not span all the states that are relevant for climate-induced risks. In this regard, there is a place for markets to issue assets with more complete state contingency, especially with regard to longer-term risks. An additional hedging complication results if shocks are very persistent or, even worse, irreversible. First, hedging such shocks requires a much greater more capital outlay, which of course is economically damaging. Here, perhaps, there is scope for more coordinated actions among many firms or even governments. Given that individual shocks need not have the same damaging consequences for every market participant at the same time, the idea of co-insurance is one that may help in the process. Finally, and probably most potently, hedging may become less problematic if the sources of risks are reduced. The idea that the asset management sector may trigger a change towards more socially responsible behaviour is somewhat realistic, but it is important to recognise that the positive feedback between the sector and major emissions producers is not something to be taken for granted.

This chapter has aimed to present a fairly comprehensive summary of the most important issues in the assessment of the asset management sector's response to natural disasters. Most empirical evidence here draws on climate-related issues, but many of the principles are more general and apply to other contexts as well. We think that one of the most important lessons is that asset managers do not operate in a vacuum. While they clearly need to build some degree of resilience into their own daily operations, it is important to recognise that the sector as a whole may drive a lot of change beyond its own scope of operations. This chapter highlights a number of positive spillovers from asset managers to the broader economy, including activism behaviour, an improved information environment or intermediation in external capital financing. To the extent that the motives of asset managers are honest and reflect the prevailing social norm, one can expect their leadership role to be an important component of the new green equilibrium. However, incentives do not always result in positive change. The idea of greenwashing, which generally covers strong profit orientation, is just one example. As such, one has to think of the best possible framework in which incentives can be aligned with the values of broader society. From a pure trading perspective, the concerted reaction to negative shocks may trigger fire sales and herding-like behaviour. While fire sales are difficult to contain ex post, risk management should strive for more separation in asset ownership across various institutions. Here, some critics point to the relative scarcity of investable liquid assets, and one can postulate more need for financial innovation and the general participation of issuers in financial markets.

Overall, the shift towards a green equilibrium is becoming a reality of the world of today and tomorrow. The adjustment will certainly be fairly dynamic. Asset managers will undoubtedly play a major role in the process and it will be very important to utilise their force in a constructive way, with the optimistic view that the end result will be a better and more sustainable world.

CHAPTER 4

Mitigating disaster risks to the financial system[140]

4.1 INTRODUCTION

Global warming will adversely affect shareholders and society by increasing the frequency and severity of natural disasters.[141] For instance, climate models point to increased frequency of, and damage from, hurricanes that make landfall.[142] Similarly, the wildfires in the Western US states and Australia are also linked to climate change.[143] Extreme temperatures, rising sea levels, hurricanes, wildfires and droughts threaten not only labour productivity but also many trillions of dollars of capital.[144] Shareholder and social welfare will be severely affected over many years as a result of these climate disasters.

In light of the failure to implement carbon emissions taxes to address global warming, there is pressure on the financial and corporate sectors to provide alternative solutions. One solution, proposed by both private actors such as large asset managers and public actors including sovereign wealth funds, pension plans and central banks, is sustainable investment mandates to incentivise firms to meet net-zero emissions by either 2030 or 2050, consistent with the goals of the 2015 Paris Climate Agreement.[145] These mandates are typically implemented as passive screens whereby a fraction of wealth is restricted to being invested in companies that meet certain sustainability guidelines. To meet net-zero targets and to qualify to be held in investors' sustainable portfolios, firms have to spend enough on measures to mitigate the effects of climate change.

Despite widely publicised pledges from financial communities, there is still considerable scepticism due to the ambiguity of these mandates. Indeed, the Biden administration is pressing the financial community to 'disambiguate' sustainable finance – i.e., to clarify these commitments.[146] In this chapter, we seek to clarify the benefits and costs of mandates that encourage firms' mitigation of the effects of global warming, from the perspective of both shareholders who subscribe to these mandates and society.

140 We thank John Hassler and Bob Litterman for their comments that helped shape revisions to this chapter.

141 See National Academy of Sciences (2016).

142 See Grinsted et al. (2019) and Kossin et al. (2020).

143 See Abatzoglou and Williams (2016).

144 The year 2020 was one of the most active hurricane seasons in the Atlantic Ocean. A record number of hurricanes made landfall, including Eta and Iota that devastated Central America. Estimates are for 5 million people displaced from the hurricanes and significant levels of property destruction that might take a decade to recover from (*New York Times*, 4 December 2020).

145 See Chapter 1 for a more extensive discussion of net-zero emissions targets, and Chapter 2 on sustainable investment mandates.

146 Zac Colman, "Kerry to Wall Street: Put your money behind your climate PR", Politico.com, 12 March 2021.

We begin by drawing some lessons from Covid-19 for natural disasters connected to global warming. After all, stock market valuations around the world crashed by nearly 30% in February to March of 2020 with the arrival of Covid-19. In contrast to the natural damages from global warming that will play out gradually over the next 100 years, the real-time experience of the world stock markets with Covid-19 offers a natural experiment to understand how climate disasters might impact the resiliency of the financial system, for both shareholders and society.

We argue that a portfolio of textbook epidemic mitigation strategies – vaccines and non-pharmaceutical interventions (NPIs) – played a quantitatively significant and under-appreciated role in stabilising the financial system from the Covid-19 shock.[147] This stands in contrast to a central narrative from the Covid-19 financial crisis that timely fiscal and monetary interventions alone safeguarded bank balance sheets and prevented a repeat of the 2008 global financial crisis.

After all, a pandemic is a natural disaster that not only threatens economic earnings growth but also increases systemic risk. Neoclassical asset pricing theory predicts that these cashflow and discount rate effects both naturally drive down asset valuations even without financial intermediation in the economy.[148] Hence, managing pandemic disaster risks to a large extent involves mitigating the medical fallout from the virus itself.

Of course, the mitigation of the natural disaster risks from climate change will not be quite the same as from Covid-19, though some scientists do argue that the spread of diseases on our planet is accelerated as a result of global warming.[149] Nonetheless, the causal link of real mitigation to the reduction of natural disaster risks to the financial system, established using the Covid-19 natural experiment, can then be used to model the cost and benefits of sustainable finance for shareholders and society when it comes to climate change.

As with the effects of Covid-19, mitigation of climate change will rely on a portfolio of measures. According to a recent IPCC special report,[150] most mitigation pathways to net-zero emissions require a portfolio of decarbonisation technologies, including negative emission technologies (NETs). Yet, traditional analysis of economic policies to address climate change is done via an IAM,[151] where the social planner accounts for externalities from carbon emissions for social welfare.

To bring out the unique aspects of mitigation spending on a portfolio of decarbonisation technologies for the financial system and the role of sustainable finance mandates, we consider an economy where capital is the only input of production and there is an externality when it comes to the mitigation of aggregate risk in order to evaluate the

147 Hong et al. (2020a)
148 See Duffie (2001).
149 Khasnis and Nettleman (2005).
150 Rogelj et al. (2018).
151 Nordhaus (2017).

social benefits of decarbonisation measures. In contrast to traditional IAMs where the tax is on carbon emissions,[152] capital is the source of the externality here and hence the tax is on capital.[153] Importantly, we model mitigation as spending on a portfolio of NETs such as afforestation and reforestation, soil carbon sequestration, bioenergy with carbon capture and storage (BECC), and direct air capture (DAC).[154]

But instead of a capital tax to achieve first best, we consider restrictions on the representative investor's portfolio, i.e., sustainable finance mandates.[155] These mandates are essentially asset portfolio restrictions to invest in sustainable companies, defined as those that spend enough to address the negative consequences of global warming. Similar to socially responsible investing from a generation earlier,[156] these mandates are meant to incentivise companies to spend on decarbonisation technologies and thus mitigate the effects of climate change through capital market boycotts. Firms that do not decarbonise enough face a higher cost of capital relative to the market, while firms that do face a lower cost of capital (i.e., a cost-of-capital wedge that substitutes for a capital tax). The benefits of the mitigation done by the subset of sustainable firms are shared by society.

In this vein, given projections of global warming and the cost of decarbonisation technologies, we calculate the fraction of wealth dedicated to sustainable firms and the cost-of-capital wedge that are needed to incentivise firms to reach net-zero targets, i.e., the mitigation spending that investments in these mandates have to subsidise. These calculations can be used to design an optimal sustainable finance mandate that speaks to the concerns of the Biden administration and others regarding the clarification of financial commitments and enforcement of stringent standards.

4.2. MITIGATING COVID-19 RISKS TO THE STOCK MARKET

After an initial sluggish response to Covid-19 in both Europe and the United States, which coincided with the Covid-19 stock market crash, countries have, to varying degrees, implemented textbook mitigation procedures. Optimal mitigation strategies entail quickly implementing vaccination programmes.[157] To the extent that vaccination takes time or is uncertain, NPIs such as social distancing or testing are used in the interim.[158] These NPIs, while protecting lives, are a costly form of mitigation since they reduce economic earnings in the short term.

152 Golosov et al. (2014).
153 Hong et al. (2020b).
154 In an earlier version of this chapter, we lumped together various forms of mitigation as opposed to highlighting NETs. As John Hassler pointed out in in his discussion of the earlier version, other forms of mitigation might increase carbon emissions in the atmosphere.
155 Hong et al. (2021a).
156 Heinkel et al. (2001); Hong and Kacperczyk (2009).
157 See Anderson and May (1992) and Bailey (1975).
158 See Behncke (2000) and Wickwire (1977).

4.2.1 Vaccines

Solving the Covid-19 pandemic and the negative economic effects has required the quick development of vaccines. The reason is that the prospect of a vaccine limits the persistence of the Covid-19 shock and thus its negative impact on long-term earnings and stock prices. But vaccine development is typically a long process, requiring 10-15 years on average. Government funding such as Operation Warp Speed (OWS), announced on 30 March 2020, fundamentally changed the process. Beyond a hefty allocation of funds for vaccine research to developers including Moderna, Sanofi, GSK, Pfizer, Novavax, Johnson & Johnson and AstraZeneca,[159] the crucial element was that the Department of Health and Human Services (HHS) built the requisite infrastructure and guaranteed the manufacturing of any successful vaccines. The HHS also purchased allotments of the vaccines prior to knowing whether any of them would be successful.[160] It changed how pharmaceutical companies assess the risk of conducting large-scale clinical trials on a new vaccine, and addressed standard externality issues when it comes to mitigation.

By mid-April of 2020 there were many candidate vaccines in development. Collectively, vaccine development across regions around the world has helped stabilise global stock prices. In other words, the reflation in asset valuations in the second half of 2020 was driven by good news regarding the effectiveness of mitigation measures.

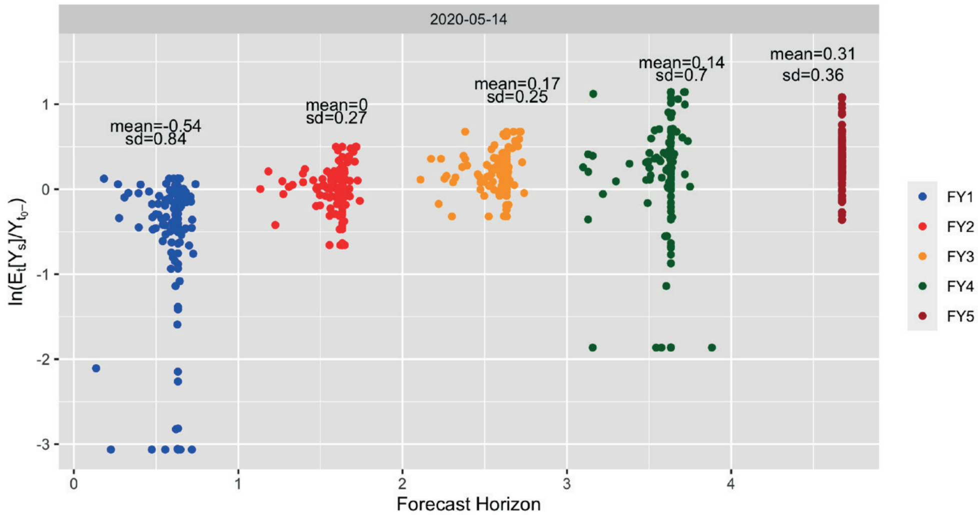
Analyst earnings forecasts

To see how this happened, we first connect the rebound in stock valuations starting around May of 2020 to increasing confidence regarding the arrival of vaccines among security analysts. This confidence can be seen in industry-level consensus analyst earnings forecasts. Security analyst forecasts should integrate the effect of mitigation on earnings, from scientific evidence on the development of effective vaccines to logistical issues surrounding their distribution as well as macroeconomic consequences to consumers and firms. Earnings forecasts in March and April of 2020 were hardly revised in the data as analysts assessed the impact of Covid-19. But by mid-May 2020, there were comprehensive revisions across all industries.

Figure 12 plots the natural log of industry-level earnings forecasts divided by pre-pandemic earnings against the horizons of the forecasts. The pre-pandemic earnings are the FY1 (one year ahead) forecasts in January 2020 discounted by growth rate forecasts in January 2020. The May 2020 cross-section is plotted. Forecast horizons are marked with different colours.

159 Bloomberg News, 23 September 2020.
160 The US government promised $20 per dose of Covid-19 vaccine (*New York Times*, 18 December 2020), which is roughly $75 billion to address Covid risks. See also Brothers (2020).

FIGURE 12 $\ln(\mathbb{E}_t[Y_s]/Y_{t0-})$ OVER FORECAST HORIZONS IN MID-MAY 2020



The FY1 forecast within 12 months before forecast end are revised down significantly, by 54% on average for the May 2020 forecasts across the industries in the sample. However, the FY2 forecasts farther out are not impacted nearly as much. Broadly, these stark differences in the revisions of earnings forecasts across horizons suggests that analysts expect a vaccine to arrive relatively quickly, since a high vaccine arrival rate (i.e. a vaccine arrives quickly and is rolled out to the population expeditiously) moderates the persistence of the Covid-19 shock to earnings.

Parsimonious earnings damage function

It is possible to then infer an earnings damage function by assuming a Poisson arrival process for the vaccine.[161] A Poisson process is defined by one parameter, λ, or the arrival rate of the vaccine.[162] This damage function connects when an effective vaccine is expected to arrive to how the Covid-19 shock should mostly be felt in short-term, as opposed to medium-term or long-term, earnings forecasts.

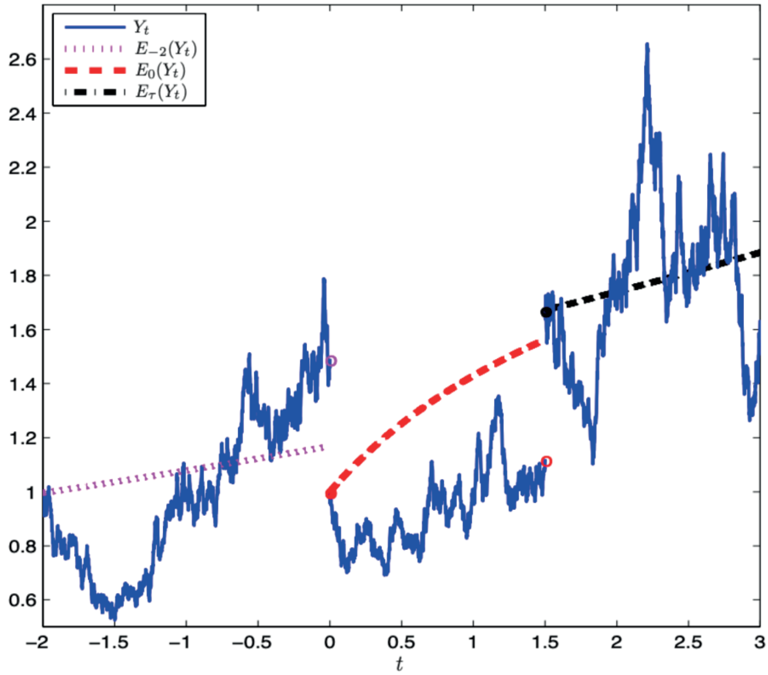
Forecasts in mid-May 2020 imply an earnings crash and lower earnings growth until a vaccine arrives in 1.48 years (95% CI [0.61 years, 5.88 years]). This 1.48-year estimate represents the fast arrival of a vaccine in historical terms and is good news for financial markets since the economic damage is fairly brief.

Figure 13 presents an illustration of this earnings damage function. The figure provides a simulated path of earnings going through the pre-pandemic period, the pandemic period, and the post-pandemic period after the arrival of the vaccine.

161 Hong et al. (2021b).

162 A Poisson process models the probability of discrete events such as the arrival of a vaccine as independent and identically distributed over the time since the last event.

FIGURE 13 **EARNINGS PATH AND EXPECTATION CALCULATIONS**



Note: The parameter vaules are: n = δ = 0.4, ĝ = 0.08, g = .85 x ĝ = 0.068, and λ = 0.67. Parameter values are annualised whenever applicable. Y_{-2} = 0.98. At time t = 0, earnings jumps from Y_{t-} = 1.492 to Y_t = 1. And at time t = 1.5, earnings jumps from Y_{t-} = 1.120 to Y_t = 1.672.

Following the evidence from analyst forecasts, we set the vaccine arrival rate at λ = 0.674 per year (with an implied expected arrival time of around 1/λ = 1.48 years after the arrival of Covid-19). The (conditional) growth rate in the pandemic regime, g, is set to be 0.85 times that of the pandemic regime, or g = 8% x 8.5% = 6.8%.

The plot starts with earnings at 0.98 at t = -2. The (continuously compounded) growth rate in the pre-pandemic period is set at 8% per annum, consistent with the median industry annual growth rate of earnings. The pandemic unexpectedly arrives at time t = 0, when earnings then jump downward from the magenta dot at 1.492 to the red solid dot at 1, which we have parameterised as the recovery fraction δ = 0.4, or a 60% initial drop in earnings similar to the significant revisions of industry earnings forecasts described above. The downward jump in earnings reflects both the sudden stop in demand as consumers take shelter and also potentially mitigation spending by firms to protect workers.

At t = 1.5, the vaccine arrives, earnings jump upwards by an amount, n. We assume that n = δ = 0.4 (and hence a 60% jump upwards in earnings when the vaccine arrives), and so earnings jump from 1.120 (the red open dot) to 1.672 (the black solid dot).

In addition to plotting a sample path, we also plot the expected earnings immediately after the pandemic arrival (see the red dashed line). Note that the red dashed line has a steep slope consistent with the data showing that short-term earnings forecasts are significantly revised downwards, while medium-term forecasts reflect the possibility of the arrival of a vaccine.

The magenta dotted line plots the expected earnings at t = -2 before the arrival of the pandemic. Similarly, the black dashed and dotted line plots expected earnings immediately after the arrival of the vaccine. That is, the earnings processes in the normal regimes (both before the arrival of the pandemic and after the arrival of the vaccine) are the same. This is an assumption built into the parsimonious earnings damage function which might not be true, i.e., post-pandemic growth rates might be lower for other reasons.

Vaccine news versus monetary and fiscal policy news.
We can estimate our parsimonious model using not just mid-May 2020 forecasts. Holding fixed the mid-May 2020 estimates of the initial jump in earnings and pandemic growth rate, we can estimate the vaccine arrival rate using June, July, and August (which are the latest available) forecasts. Differences in the estimated vaccine arrival estimates across the months pick up news on vaccine development.

Whereas the estimated arrival rate for mid-May 2020 is 0.674, the estimates are 0.741, 0.815, and 1.636 for June, July and August, respectively. The 1.636 estimate for August stands out and its 95% bootstrap confidence interval for this estimate is [0.94, 2.83]. This translates into an expected arrival time of 0.61 years, which is significantly quicker than the 1.48 years implied by the May forecasts. The arrival rate estimate for August of 1.636 essentially lies outside the confidence intervals for May [0.17, 1.65], June [0.45, 1.23], and July [0.5, 1.35] (1.636 is just inside of 1.65). Moreover, the estimates for May, June and July also lie outside the confidence interval for August.

Importantly, there was little fiscal or monetary news in July and August of 2020, but there were two key pieces of news regarding the clinical trials by Moderna and Pfizer that came up in late July and early August.

4.2.2 NPIs

In contrast, the roll out of NPIs has been more problematic, often erroneously framed as sacrificing the economy to save lives.[163] In fact, there are also substantial benefits in terms of economic earnings from such costly mitigation. Purely value-maximising firms with access to a mitigation technology find it optimal to spend on costly NPIs even holding fixed their expectations of a vaccine arrival. The main reason is that a highly contagious and unpredictable virus is also a threat to earnings growth even in the short term, since explosive infection rates mean unproductive workers and supply-side bottlenecks.

Stochastic SIS versus deterministic SIR

To work out this implication, we need a model of Covid-19 risk. Typically, epidemiologists use a Susceptible-Infected-Recovered (SIR) model, since there is some period of immunity for those who have recovered from the virus. As John Hassler points out in his discussion of this chapter, a deterministic Susceptible-Infected-Susceptible (SIS) model infection forecast overshoots that of a deterministic SIR model depending on how long recovered patients remain immune.

But deterministic SIR models do not perform well when it comes to actual forecasting since transmission rates are highly stochastic.[164] It is clear based on the experience of Covid-19 that stochasticity of transmission shocks is key to generating accurate forecasts. Another downside of an SIR model is that it is difficult to tractably introduce uncertainty in transmission rates into this model and still conduct economic calculations due to the need to keep track of an extra compartment of recovered individuals. But a tractable virus process is needed to lay out the risks and implications for mitigation transparently in an asset pricing setting.

As such, we will work with an SIS model with stochastics. Our stochastic model can generate forecasts of infection levels more accurately than a deterministic SIR model since transmission rates are, in reality, highly variable.[165] At the same time, the model is highly tractable, allowing for transparent economic calculations.

Basic reproduction number

The most widely reported statistic when it comes to Covid-19 is its basic reproduction number, R_0, defined as the expected number of secondary infections generated by a single (representative) infected individual in a fully susceptible population.[166] This comes from a classic epidemic model,[167] where the virus is transmitted through meetings of

163 For instance, Lt Governor Dan Patrick of Texas, aged 69, said on the Tucker Carlson show on 24 March 2020, "Those of us who are 70 plus, we'll take care of ourselves. But don't sacrifice the country."

164 See Dureau et al. (2013).

165 See Hong et al. (2020a) for how stochastic transmission rates impact the accuracy of deterministic model approximations.

166 Lockdown and mitigation decisions by epidemiologists and economists pivot on R0, as discussed in Imai et al. (2020).

167 Kermack and McKendrick (1972).

infected with uninfected individuals. The probability that an infectious individual meets a susceptible individual is proportional to the product of their population mass, $I_t\ (1\text{-}I_t)$, where I_t is the mass of the infected and $(1\text{-}I_t)$ is the mass of the uninfected and hence susceptible. Over the interval [t,t+dt), the total number of new infections is

$$\beta\ dt\ I_t\ (1 - I_t) \qquad (1)$$

where β denotes the transmission rate.

The basic reproduction number, R_0, is then given by the ratio of the transmission rate β and the recovery rate γ as infected individuals recover and become uninfected:

$$R_0 = \beta/\gamma \qquad (2)$$

If $R_0 \leq 1$ (when $\beta \leq \gamma$), the disease is eventually extinct, while if $R_0 > 1$, the infected population I_t eventually reaches the maximum level, $I_\infty = 1\text{-}R_0^{-1} > 0$. The higher the reproduction number, the worse the steady-state level of infections in the population.

Stochastic transmission rates

Yet, epidemiologists recognise that this model is a crude approximation of epidemic dynamics, which are in reality stochastic. Aggregate transmission rate shocks due to environmental factors or virus mutations can play a large role in the evolution of infection dynamics.[168] A case in point is the resurgence of Covid-19 in a number of countries during the summer of 2020, including countries with prudent mitigation such as South Korea. A more recent example is the concerns regarding mutations such as those in the United Kingdom and South Africa associated with the Covid-19 wave in the late autumn of 2020.

A simple way to model stochastic transmission is to replace the constant rate β dt in Equation (1) with $\tilde{\beta}$ dt, following Gray et al. (2011), where

$$\tilde{\beta}\ dt = \beta\ dt + \sigma\ dZ_t. \qquad (3)$$

Z_t is a standard Brownian motion, i.e., independently and identically distributed (i.i.d.) random variables that capture shocks to the transmission rate, and σ is the transmission volatility parameter.

168 Dureau et al. (2013).

Early Covid-19 dynamics

Estimates of β, σ and R_0 across regions are typically obtained using January–February 2020 infections data from a sample of countries (regions) that were at high risk due to air travel connected to China.[169] The sample comprises a total of 16 countries/regions. In Asia (Middle East), the nine countries/regions are China, Japan, Malaysia, Singapore, South Korea, Taiwan (China), Thailand, United Arab Emirates and Vietnam. The Western countries are Australia, Canada, France, Germany, Italy, the United Kingdom and the United States.[170]

One starts with estimates of β and σ for each region using that region's brief time series, and then obtains an overall estimate using the mean of these values across the 16 regions weighted by the number of daily observations in each region. For instance, China has more observations in this period and thus gets more weight in the overall estimate. Since most mitigation responses only started in March 2020, these estimates are representative of the underlying disease process or early Covid-19 dynamics absent any mitigation responses.

The mean estimate of β from the January–February sample is 6.616 per month with a 90% confidence interval (CI) of (2.443, 14.168). The expected duration for an infected and infective individual is around 14 days, which implies that the rate γ is equal to 1/14 per day, or $\gamma = 365/12/14 \cong 2.173$ per month. Hence, the estimate of the basic reproduction number R_0 is then $3.045 \cong 6.616/2.173$, with a 90% CI of (1.12, 6.52). This reproduction number is comparable to that of the 1918 Spanish Flu.

While all these countries have significant air travel connections to China, they did not experience the same infection path. The mean estimate of σ from the January–February sample is 2.851 per month, with a 90% CI of (0.718, 8.857). The implied estimate of σ is then 1.689 per month. This is consistent with each country experiencing idiosyncratic paths (realisations) of transmission shocks at early stages due to σ.

Market price of risk

In short, Covid-19 is not only contagious (high R_0) but the community transmission rates are highly unpredictable due to environmental factors or mutations (large σ). Hence, these transmission shocks are at least a regional risk factor. But evidence over the past year suggests that there are also commonalities in the behaviour of Covid-19 across regions, such as in mutations. Hence, it is also a potentially important systemic risk factor that will affect all firms' discount rates.

169 Kucharski et al. (2020).

170 The list of countries is based on most frequent air connections to China. Hence, some European countries with high infections, such as Spain, are not on the list.

Typically, when one considers what drives discount rates for firms, one thinks of business cycle factors. With Covid-19, there is a new systemic risk factor – namely, the uncertain transmission rate – which ought to be priced in the cross-section of stock returns. This stochastic transmission risk rationalises the financial damage of the sort mentioned by the Federal Reserve Board: "Asset prices remain vulnerable to significant price declines should the pandemic take an unexpected course…".[171]

Counterfactual absent costly NPIs

Hence, even when fixing the optimistic expectations of a vaccine, a calibration[172] based on the unpredictability of a contagious Covid-19 suggests that stock markets would still have been 15% lower absent firms' NPIs to protect their workers. In other words, vaccines in of themselves are not enough to stabilise stock markets. This explains why leading companies such as Microsoft were the first to disperse their workforce even before government actions. Indeed, reports suggest that it was these early corporate NPIs that triggered local governments to move on them as well, thereby also addressing potential externalities associated with NPIs.[173]

Companies like Amazon in essential industries that need their workers to staff supply chains ended up spending billions on other Covid-19 mitigation responses such as testing for their workers, in the case of Amazon wiping out the company's Q2 profits.[174]

When firms took precautions to mitigate Covid-19 risks early – such as testing employees, implementing social distancing protocols, and implementing health checks – they may have faced initial losses, but in the long run they performed better than those that did not mitigate.

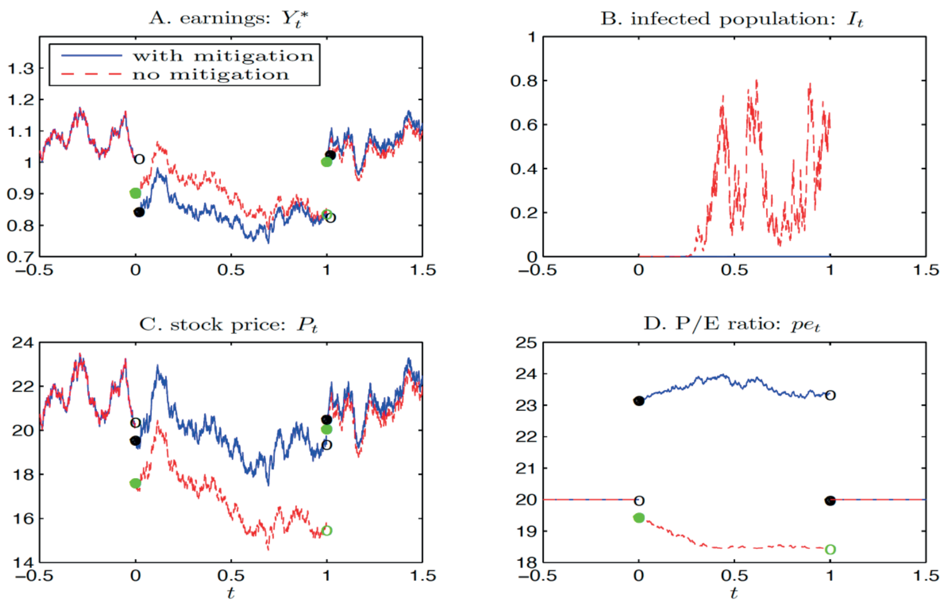
While these NPI interventions led to a severe downward jump in corporate earnings (nearly 50% on average), they helped stabilise stock prices, which ultimately depend on long-run earnings growth. It is interesting to note that during the 1918 Spanish Flu, societies did not really believe in social distancing as an effective mitigation tool and hence it was much less used than today.[175] For companies without access to mitigation, such as those in the meatpacking industry, Covid-19 infections have severely impacted both worker productivity and stock prices.[176]

171 Federal Reserve Board (2020).
172 Hong et al. (2020a).
173 Weise (2020).
174 Source: *MarketWatch*, reported on 2 May 2020.
175 Hatchett et al. (2007).
176 Taylor et al. (2020).

Beyond these anecdotes, we present a calibration to quantify the value of such costly mitigation even assuming a relatively optimistic vaccine scenario. This calibration takes the parameters characterising the early dynamics of Covid-19 described above. It also takes as given the vaccine arrival rate inferred from analyst forecasts, along with pre-pandemic earnings growth from historical data. In calculating the stock market price, we assume that firms are maximising share price when determining their optimal costly mitigation spending.

We demonstrate the effect of mitigation via a counterfactual in Figure 14 of what would happen to stock prices absent mitigation by the firm. The red lines represent this no-mitigation counterfactual. First, notice that at t = 0, earnings (net of mitigation costs), Y_t^*, fall less when the firm does not mitigate. Y_t^* nonetheless falls since some customers withdraw purchases. Moreover, because the firm does not mitigate, the infection rate is much higher, as one can see from panel B. The earnings level with mitigation is initially lower than if the firm did not mitigate. However, earnings under the no-mitigation scenario deteriorate more than under the mitigation scenario. This of course is because infections get out of control, with about 80% of the population infected at t = 0.6 in this simulation. This higher level of infections damages earnings growth.

FIGURE 14 **COUNTERFACTUAL ANALYSIS**



Note: This figure compares simulated paths for earnings (net of mitigation costs) Y_t^*, the infected mass I_t, stock price P_t and price-to-earnings ratio $pe_t = P_t/Y_t^*$ with and without mitigation. Panel A shows that mitigation lowers earnings during the pandemic period but raises post-pandemic earnings. Panel C shows that mitigation increases stock price, and panel D shows that the price-to-earnings ratio with mitigation, pe_t, is higher during the pandemic than during the pre- and post-pandemic periods.

Once the vaccine arrives (in our simulation, at $t = 1$), earnings actually jump more and are higher with mitigation than without. Because the stock price is proportional to earnings in the post-pandemic regime, it also jumps more with mitigation than without at $t = 1$. In summary, the mitigation strategy outperforms the non-mitigation counterfactual because earnings and prices are higher under the mitigation scenario when the vaccine arrives.

As a result, the stock market absent mitigation would be down by about 15% relative to the stock price under the optimal mitigation policy (panel C). In contrast to the mitigation scenario, where the *pe* ratio hovers at around 23.5, the *pe* ratio is below 20 in the no-mitigation counterfactual (as seen in panel D) due to various channels (damage to earnings growth and higher risk premiums for stochastic transmissions). Hence, mitigation leads to less damage to stock markets. In this calculation, aggregate transmission shocks serve as an important source of elevated risk premiums and stock market volatility.

Our analysis can give an account of asset price dynamics – the dramatic plunge in the stock market in late February 2020 and equally dramatic rebound in late March 2020. An oft-cited explanation for the rebound, as we discussed in the introduction, is that unexpected government intervention helped alleviate elevated risk premiums due to Covid-19. But interventions by the Federal Reserve Bank in credit markets also coincided with a strong mitigation response by society via social distancing.

Our analysis also points to another explanation. Investors might have thought that society would be unlikely to control the virus initially (which corresponds to poor priors on an effective vaccine timeline and the counterfactual of no firm mitigation) but subsequently learned that control of the pandemic was likely (and hence the market rebounded to the equilibrium prices under optimal mitigation).

4.3 DECARBONISATION AND CLIMATE DISASTERS

We next apply lessons from the causal impact of mitigation measures on reducing Covid-19 risk to the financial system to the problem of global warming. Unlike Covid-19, the damage from these natural disasters will affect not only labour but also capital. For instance, extreme heat events affect labour productivity, while rising sea levels and hurricanes threaten trillions of dollars of both physical and housing capital. But like Covid-19, firms will need to spend on a portfolio of decarbonisation measures, including NETs, to mitigate the effects of global warming. In light of this evidence, we seek to clarify the benefits and costs of sustainable finance mandates in reducing natural disaster risks from global warming for the financial system.

Business-as-usual estimates

We begin with projections from both climate scientists and economists for the path of GDP growth under a business-as-usual scenario. These projections start with a set of panel regressions documenting the adverse effects of exogenous annual changes in temperature (i.e., weather shocks) for economic growth.[177] This panel regression approach initially focused on how weather affects crop yields[178] by using location and time fixed effects, but has now been applied to many other contexts including economic growth and productivity.

The main idea is that extreme annual temperature fluctuations are shocks that causally trace out the impact of higher temperatures on output. The panel specification from the weather economy literature is given by:

$$y_{i,t} = \beta \text{ Temperature}_{i,t} + \chi_i + \eta_t + \varepsilon_{i,t} \tag{4}$$

The dependent variables of interest, y, as in the literature is either annual GDP growth rate or capital investment. The independent variable of interest is Temperature. The subscript i is for country, and t denotes the year. The country fixed effects, χ_i , absorb fixed country characteristics, whether observed or unobserved, disentangling the temperature shock from many possible sources of time-invariant omitted variable bias. The time-fixed effects, η_t, further neutralise any common trends and thus help ensure that the relationships of interest are identified from idiosyncratic local shocks. And $\varepsilon_{i,t}$ is the error term.

The potential impact of warming on national and global incomes can then be quantified by combining these estimated response functions (which can also be modelled as non-linear as opposed to linear functions) with 'business as usual' scenarios (representative concentration pathway, or RCP, of 8.5) for future warming and baseline growth assumptions based on a historical sample period (for example, 1960–2010). This approach assumes that future economies will respond to temperature changes similarly to today's economies.

In long samples starting from 1960, this new weather economy literature finds that a temperature rise in the range of 2°C lowers GDP growth rates and, to a lesser degree, capital investments. Using these regression estimates, a gloomy projection[179] is that, absent mitigation, median global GDP per capita in 2100 will be 76.3% of what it was in 2010. In other words, GDP per capita in 2100 is 23.6% lower compared to 2010 due to global warming absent mitigation. This maps into an annual GDP per capita growth rate of -0.3% (i.e., (1-0.3/100)90 is roughly 0.763, where 90 corresponds to the years of compounding between 2010 and 2100).

177 Dell et al. (2014).
178 Schenkler and Roberts (2009).
179 Burke et al. (2015).

Caveats on a wide range of business-as-usual estimates

As Bob Litterman points out in his discussion of this chapter, there are a wide array of business-as-usual estimates, from there being little effect of climate change to scenarios far worse than the -0.3% figure we discuss. John Hassler also points out that Burke et al.'s (2015) reliance on non-linearity might generate counterfactual implications for certain countries. Nonetheless, their estimates are widely used and their methodology is easy to apply. We do not have much to add to this discussion other than it is with these caveats in mind that we conduct our calculations below.

Mapping to a disaster model with mitigation

Since extreme annual temperatures and the damage to the economy are related to weather disasters,[180] these business-as-usual projections can be mapped into a disaster model with a few assumptions.

In this model, which follows Pindyck and Wang (2013), a climate disaster event follows a Poisson process with an arrival rate λ. The arrival of a disaster destroys a fraction (1-Z) of the capital stock, where Z is the recovery fraction following a disaster. Assuming the distribution of Z follows a power law with parameter β_0, the expected fractional capital loss conditional on a disaster arrival, $l(\mathbf{x})$, is given by

$$l(\mathbf{x}) = 1/(\beta_0 + \beta_1\, \mathbf{x} + 1). \tag{5}$$

The larger the mitigation spending $\mathbf{x}$, the smaller the expected fractional loss from a disaster due to mitigation.

We set β_0 =100, which matches the loss distribution for a weather disaster such as a major hurricane that makes landfall. Absent mitigation (x=0), the implied expected fractional capital loss is $l(0) = 1/(\beta_0 + 1) = 1/101 = 1\%$. For reasons of tractability, we put all the damage from climate change into damage to capital. More realistically, global warming will also adversely affect productivity.

For a given $\mathbf{x}$, expected damage to the aggregate growth rate is given by $\lambda\, l(\mathbf{x})$, the arrival rate of disasters multiplied by the loss conditional on an arrival. Absent mitigation (i.e., $\mathbf{x}$ = 0), and assuming a historical rate of investment per annum, a jump arrival rate λ = 4.19 per annum or a weather disaster that is expected once every few months is needed to match the -0.3% growth rate per annum figure from our climate change projections above.

Since global warming affects both arrival rates of and losses from weather disasters, we have chosen a formulation with more frequent moderate weather disasters. In an earlier version of this chapter, we considered an alternative formulation along the lines of Barro and Jin (2011) using rare disasters (i.e. a low arrival rate and high losses conditioned on

180 Auffhammer et al. (2013).

arrival). A rare disaster every seven years generates a similar expected loss profile to our more frequent but smaller disasters. As John Hassler has pointed out in his discussion, however, it is more likely that damages will manifest with more frequent smaller disasters than a rare large one.

From the perspective of our model, all that matters is the expected loss, which is pegged to Burke et al.'s (2015) projections. For the purposes of modelling, we put all of the damage from climate change into natural disasters. In reality, the damage might also manifest as shocks to labour productivity. Nonetheless, our estimates are in line with capital damage estimates from more frequent and damaging hurricanes absent mitigation from Hsiang and Jina (2014).

Mitigation spending on decarbonisation technology

According to estimates from a McKinsey sustainability report,[181] decarbonisation of just the heavy industries such as cement, which account for 20% of the global carbon emissions, will cost around $20 trillion up to 2050 (or $0.75 trillion dollars per year). Each year, the entire global industrial sector emits around 50 billion metric tonnes of greenhouse gases.

Estimates of carbon capture vary greatly depending on location and might be as low as $60–100 per metric tonne.[182] As a baseline scenario, we suppose that cost of the portfolio of decarbonisation technologies over the next 30 years reaches either $144 per metric tonne (low cost) or $288 per metric tonne (high cost). This would mean firms need to spend $3.67 ($7.4) trillion annually on decarbonisation, or 0.6% (1.2%) of the $600 trillion dollars of global capital stock. Of course, similar to the business-as-usual projections, there is significant uncertainty over the path of NET prices over the next century.[183]

We then calibrate the parameter β_1 as follows. Suppose that aggregate mitigation spending of $\mathbf{x}$ = 0.6% is able to stop the rise of global temperature and that the expected growth rate is not as severely damaged as it otherwise would be absent mitigation. There is in general uncertainty over how the abatement of temperatures will translate into the mitigation of damages. We pick 1% per annum as a baseline scenario and consider some alternative targets (ranging from 0.25% to 1.25%) in the comparative statics. For our baseline, this yields $\beta_1 = 8.9 \times 10^3$.

Competitive versus planner economy

The value of this technology is likely to be large given realistic household risk preferences[184] and evidence from the large macro-finance literature[185] on the permanence of disaster shocks on risk premiums in stock markets. This long-run risk set-up has also been used in recent integrated assessment models.[186] We focus on a calibration of a

181 de Pee (2018).
182 Schmelz et al. (2020).
183 See Gates (2021) for a discussion of costs of NETs.
184 Epstein and Zin (1989).
185 Bansal and Yaron (2004).
186 Daniel et al. (2019).

business-as-usual economy with a negative growth of -0.3% per annum due to global warming, as described above. This calibration emphasises the difference in social welfare in a competitive economy (with externalities and no mitigation spending) compared to a first-best economy (without externalities and optimal mitigation spending).

TABLE 2 **COMPARING COMPETITIVE MARKET SOLUTION WITH FIRST-BEST**

A. Competitive market outcomes		
Mitigation level	x	0
Aggregate investment	i	12.65%
Aggregate consumption/dividends	c	9.35%
Expected GDP growth rate	g	-0.3%
(Real) risk-free rate	r	0.82%
Stock market risk premium	$r^M - r$	4.09%
Stock market return volatility		14.30%
Tobin's q	q	1.79
B. First-best outcomes		
First-best mitigation level	x^{FB}	1.72%
Aggregate investment	i^{FB}	11.75%
Aggregate consumption/dividends	c^{FB}	8.53%
Expected GDP growth rate	g^{FB}	1.68%
(Real) risk-free rate	r	2.76%
Stock market risk premium	$r^M - r$	3.95%
Stock market return volatility		14.05%
Tobin's q	q^{FB}	1.70

Note: All parameter values, whenever applicable, are continuously compounded and annualised.

In Table 2 we report outcomes of the variables of interest for the competitive equilibrium (Panel A) and the first-best outcome (Panel B). First, consider the competitive equilibrium outcomes in Panel A. There is no aggregate risk mitigation (i.e., $\mathbf{x} = 0$). The growth rate, g, is negative at -0.3% per annum by construction. The market risk premium is 4.09% per annum and the real risk-free rate is negative (0.82% per annum). In addition, the implied Tobin's q (the ratio between a physical asset's market value and its replacement value) is 1.79 and annual stock market volatility is 14.30%.

Now consider the first-best outcomes in Panel B. The first-best level of mitigation is $\mathbf{x}^{FB} = 1.72\%$ per annum. Mitigation spending makes the economy more sustainable, turning the aggregate (expected) growth rate positive at 1.68% per annum (from -0.3% per annum in Panel A). Compared with the competitive equilibrium results in Panel A, in the first-best planner's economy the real risk-free rate is significantly higher (2.76% per annum), and the equity risk premium is only mildly lower (3.95% per annum). While aggregate risk mitigation costs 1.72% of the capital stock each year, causing both consumption and investment to be lower than in the competitive market economy, optimally mitigating aggregate risk nonetheless enhances welfare and generates sustainable growth. Social welfare is nearly 36% higher in the planner economy than in the competitive market economy.

4.4 SUSTAINABLE FINANCE COMMITMENTS NEEDED TO ACHIEVE NET ZERO

In this final section, we examine the extent to which these mandates can move us from the competitive equilibrium outcomes in Panel A of Table 2 to the first-best outcomes in Panel B of Table 2. Most of these mandates are implemented as passive screens, whereby a fraction of stock portfolios are restricted to investing in companies that meet certain thresholds of sustainability. The underlying premise is that these mandates are meant to incentivise companies to mitigate the effects associated with climate change through capital market boycotts.

Estimates

According to Hong et al. (2021a), the amount of sustainable capital and the welfare-maximising qualification criterion needed to achieve targeted decarbonisation spending depend on a firm policy requiring a certain fraction of cashflows to be paid out as dividends. With the restriction that a firm pays around 35% of its revenues as dividends (roughly the payout ratio for mature consumers or industrial companies), achieving the net-zero target aggregate spending of 0.6% of capital stock per annum requires (i) that 38% of wealth be allocated to mandates, and (ii) a qualification criterion requiring the firm to spend 1.6% of its capital stock each year on mitigation. The compensating cost-of-capital advantage for a sustainable firm over an unsustainable one is 0.90% per annum. A higher dividend payout requirement implies that first-best can only be achieved with a greater fraction of wealth committed to mandates, since these sustainable firms can spend less on mitigation. Sufficiently large dividend payout requirements may mean mandates cannot achieve first-best, since firms ultimately cannot spend much on mitigation.

As we vary the effectiveness of decarbonisation technologies in limiting damage to economic growth, we find fairly similar financial commitments. However, as we increase the cost of decarbonisation technologies – i.e., suppose that net-zero targets require spending of 1.2% as opposed 0.6% of capital stock on decarbonisation measures – then the amount of sustainable capital needed increases substantially (from 38% of wealth to 61% of wealth) and so does the cost-of-capital wedge (from 1.6% to 2%).

How mandates work in practice

One common critique of sustainable investment mandates, also echoed in Bob Litterman's discussion of this chapter, is the potential for investors who do not care about them to short the high-price sustainable stocks and buy the low-price unsustainable stocks. In practice, there are substantial limits to arbitrage that make demand curves for stocks highly inelastic[187] and hence mandates effective in incentivising firm mitigation. Of course, to the extent that such sustainable finance mandates become important, new forms of arbitrage might arise. But at the same time, it is also feasible to design sustainable finance mandates in such a way as to limit the scope for such arbitrage (for example, by not allowing sustainable firms' shares to be loaned out for short-selling).

4.5 CONCLUSION AND POLICY IMPLICATIONS

In this chapter, we point out the importance of mitigation spending in protecting the financial system from natural disasters. We start by quantifying the under-appreciated role of textbook epidemic mitigation strategies in stabilising the financial system following the Covid-19 shock. We then quantify the extent to which sustainable finance mandates to subsidise firm mitigation in decarbonisation technologies can provide an alternative solution to global warming in lieu of carbon taxes.

Sustainable finance mandates are an order of magnitude too small

There are many ways to check the commitment of sustainable finance in our framework, whether it is disclosure of firm-level mitigation spending or using the cost-of-capital wedge as a proxy for the costs that shareholders are bearing to fund mitigation. One implication of our analysis is that for sustainable finance to confront the climate change problem, it has to be different than what has been labelled 'sustainable finance' in the past.

187 Shleifer (1986), Chang et al. (2015), Koijen and Yogo (2019).

The share of assets under management devoted to sustainable funds has averaged 20% over the last 20 years. Over a long sample period, there is little evidence that there are significant differences in the cost of capital for sustainable versus unsustainable firms.[188]

According to our model, this means that the sustainable finance mandates are an order of magnitude too small, or equivalently the qualification criterion for be a 'sustainable' firm is not stringent enough. However, evidence based on return differences for high- versus low-carbon emissions companies over the last few years[189] suggests that the qualification criterion might be getting more stringent.

188 See Matos (2020) for a review of the evidence.
189 Bolton and Kacperczyk (2020).

CHAPTER 5

Discussions

5.1 DISCUSSION OF CHAPTER 1, "NATURAL DISASTERS, CLIMATE CHANGE, AND CENTRAL BANKS", BY SYLVIE GOULARD [190]

The chapter on "Natural disasters, climate change and central banks" is very rich and stimulating. I cannot hope to mention all the aspects the authors tackle, so I will instead focus on three areas, going beyond the technical aspects:

- the role of central banks as lenders of last resort and our appreciation of risks;
- the scenario analysis as an indicator of our relation to time; and
- the net zero concept (what it means for central banking and supervision and, beyond that, its meaning for broader society and geopolitics).

Should central banks systematically intervene in a financial crisis and act as lender of last resort (LOLR) to provide stability? Current mainstream thinking considers that their intervention should be taken for granted. In particular, in 2020 during the first phase of the Covid crisis, it was seen as indispensable that they provide huge amounts of liquidity. In Europe, after a short hesitation, the ECB Governing Council decided to create the Pandemic Exceptional Purchase Programme aimed at reducing financial turbulence and stabilising the markets.

Many commentators insisted that the 2020 interventions would not create moral hazard as all EU countries were hit, to varying degrees, by an external shock – the spread of a new virus. Nobody can deny that there is a difference between the global financial crisis, caused by mismanagement in the financial sector, and a health crisis. Nevertheless, it is worth examining what happened and worth doing so with the independent mindset of this chapter.

The chapter underlines that even if banks were better capitalised in 2020 than in 2008, their balance sheets were not strong enough to avoid such intervention at a massive scale. The authors remind us that in the United States, investors' flight to safety created troubles in the money markets. The same was true for Europe as well; in France, for example the commercial paper market experienced heavy turbulence.

190 These comments are drafted in a personal capacity and do not represent the views of the Banque de France.

According to the chapter, two lessons should be drawn from this experience: first, that "natural disasters can severely affect economic activity and quickly destabilize finance"; second, that "the policy response to stabilize the financial system should avoid an excessive reliance on central bank backstops. LOLR interventions should not become the default intervention to stem a financial crisis."

Since Mark Carney's landmark speech in September 2015,[191] central banks have slowly been recognising their responsibility to assess, price and mitigate climate-related risks. The Network for Greening the Financial System (NGFS),[192] which was launched in 2017 with eight members, now includes more than 90 central banks and supervisors worldwide, including the Federal Reserve. This coalition of willing members is meant to encourage cross-border technical exchanges of views, provide joint analysis and develop open source tools for supervisors and central bankers, such as net zero scenarios. The NGFS has helped increase awareness of climate-related risks and their consequences for financial stability, helped scale up green finance and helped promote green monetary policy. It works closely with the IMF, the European Commission and other stakeholders such as NGOs and scientific bodies.

Losses related to biodiversity and natural capital are increasingly seen as new sources of risk; they have been studied by the OECD[193], the Dutch National Bank,[194] and more recently in the Dasgupta review[195] that was drafted for the UK government. Health-related risks are not yet in the scope of central banks, but two high-level groups launched after the Covid-19 crisis have begun to think about the best way to mitigate risks that were severe enough to justify lockdowns and activity interruption. The first is the WHO–Europe Pan-European Commission on Health and Sustainable Development chaired by Mario Monti, which produced a first Call to Action in March 2021,[196] and the second is a High-Level Independent Panel on Financing the Global Commons for Pandemic Preparedness and Response, created by the Italian G20 presidency[197] and chaired by Tharman Shanmugaratnam.

Many debates are taking place around the respective responsibilities of elected governments and technical institutions, such as supervisors and central banks, in tackling climate change. In particular, there are lots of discussions around the question of mandates. Do they allow 'green quantitative easing' or, at least, the selection of 'green' collateral instruments? Or should these institutions remain 'market -neutral' and refrain from taking the 'greenness' of bonds and other financial instruments into consideration? Usually, the role of central banks in stabilising the financial markets – whatever happens

191 See www.bankofengland.co.uk/speech/2015/breaking-the-tragedy-of-the-horizon-climate-change-and-financial-stability.
192 See https://www.ngfs.net/en.
193 OECD (2019).
194 DNB and PBL (2020).
195 HM Treasury (2021).
196 WHO (2021).
197 See www.mef.gov.it/en/ufficio-stampa/comunicati/2021/The-G20-establishes-a-High-Level-Independent-Panel-on-financing-the-Global-Commons-for-Pandemic-Preparedness-and-Response-00001/

– is subject to little questioning. Rarely is the LOLR role of central banks put into question in the way that the authors do in this chapter. They quote Jean Tirole, who is one of those who consider that some governments are not doing enough to respect the Paris Agreement, leaving financial supervisors and central banks to deal with the consequences of their inaction.

They are both right to question the meaning of these interventions in quasi-philosophical terms. If natural disasters – including climate events – are expected to happen more frequently and become more dangerous, how can we protect ourselves, our societies and our economies from the turbulence deriving from them? Isn't it the mission of elected governments to prevent such events, by introducing ex ante the fair pricing of negative externalities, be they CO_2 emissions, biodiversity destruction or health unpreparedness? And shouldn't accountable governments use fiscal measures and tax incentives or sanctions to encourage action by companies and households?

The authors go beyond this, asking: Should the lack of prevention be compensated by ex-post action, such as the stabilisation of the markets? Or is it also the duty of insurers, knowing that some events are too severe to be covered by traditional insurance mechanisms? Could we therefore invent new public or private hedging instruments?

In a book called *The Green Swan: Central banking and financial stability in the age of climate change*, published in January 2020, researchers from the BIS and the Banque de France, including Patrick Bolton, tackled some of these questions as far as climate-related events are concerned. The book was published before the pandemic, and we have since come to realise that *green swans* have features in common with a health crisis. "Natural catastrophes", to take the excellent wording of the chapter, share the same magnitude. They are vital threats. They are predictable, even if no one can announce when they will happen. To hedge oneself alone against such events is impossible and the fact that they are non-linear creates unprecedented risks for societies and economies.

The truth is that we are far from properly pricing – or we are simply not properly pricing – the risk deriving from climate change and other potential large catastrophes. We live as if they will not happen although in a time of global mobility, increased demographic pressure and destruction of natural habitats, they could occur more frequently and have larger, global effects. As they are likely to happen, we should anticipate and see that they could create economic trouble, with consequences for financial markets. The chapter is right when it invites us to think 'out of the box' and not trust that the traditional tools, including the stabilising role of central banks, will be sufficient.

In a nutshell, the existence of lenders of last resort cannot mean that there is a 'planet of last resort'. Nor does it mean that we can avoid dealing in depth with the causes of these events and just intervene to limit damage ex post.

The two other very interesting aspects of the chapter's reflections have to do with net-zero scenario analysis and its consequences for time. With climate change, the future cannot be an extrapolation of the past. It is such a disruption that our traditional perception of time has to be transformed. Not only is the need for long-term thinking increased – beyond the schedules of democratically elected governments or central banks' and supervisors' usual horizons – but we need to understand that our current actions impact the future because it requires an acceleration of transition. The later we act, the worse the physical consequences will be. But the sooner we act, the larger the transition risks become.

The net-zero approach requires new, forward-looking analysis. The question is no longer "What is my impact on the planet?" but "What is my business plan to definitely stop emitting in 2050?". Companies are supposed to change the way they produce goods, but also the way they organise their supply chain and sell their products. The same for citizens, whose daily lives need to be modified in areas including transportation, food and energy consumption, as well as housing, entertainment and trips. If we are serious about the net-zero commitment, the disruption is an extreme one.

In the spring of 2021, the Banque de France will publish the results of the first pilot stress tests conducted with banks and insurance companies based on NGFS transition scenarios. This is a voluntary endeavour from the industry – a first attempt to think with a net-zero perspective. Other central banks, such as the Bank of England, have engaged in similar experiences. It will not be a once-and-for-all exercise but more a series of attempts, aiming at permanently improving the scenarios and tools available and drawing lessons from initial flaws or failures.

Not only does our relationship to time have to change; we also need to learn how to deal with more complex, unprecedented risks.

We know little about the interaction between different ecosystems. For this reason as well, we cannot use backward-looking data. For example, increased sea temperatures have an influence on coral reefs, which themselves impact fish species and human life in coastal regions. We need to take into account that risks are non-linear and that in-depth interactions exist between climate change, loss of biodiversity and human health. In this regard, the One Health concept promoted by the WHO, which invites us to look at human health, animal health and nature together, is key.

Finally, in a net-zero perspective, we should ask ourselves if we should allow polluters to continue under the condition that they pay for the damages (or buy some polluting rights) or if instead we should impose emission reductions, at least as long as technological change does not allow safe carbon capture? As the European authorities stress, the transition should be fair and affordable for all. We already know that in an open, globalised world, carbon 'leakage' is a scourge – if a jurisdiction is isolated in pushing regulation too far, according to regulatory arbitrage the activity will move elsewhere, with no benefit for the planet.

The chapter makes interesting proposals such as a “global reporting framework” which could, in the authors’ opinion, be put in place by the NGFS. Companies would be required to report their emissions but also their future projected emissions up to a three-year horizon. It also suggests that disclosure by financial institutions should include their carbon footprint on an annual basis and their commitments to decarbonise their portfolios or balance sheets.

The message of this chapter can be summed up in one sentence: “Climate risk is a source of risks that is fundamentally different from the financial risks investors and financial regulators are used to managing.” It rightly insists on the societal dimension of climate change – a phenomenon which requires the transformation of society and governance as well as individual behaviour. Furthermore, the geopolitical consequences of global warming, with extreme temperatures and humidity to be experienced in many parts of the world, cannot be underestimated, as the chapter demonstrates.

5.2 DISCUSSION OF CHAPTER 1, “NATURAL DISASTERS, CLIMATE CHANGE, AND CENTRAL BANKS”, BY SABINE MAUDERER

Introduction

This chapter provides an excellent overview of the latest research findings on climate change-related risks, and it also reinforces the need for immediate action. Furthermore, it reflects the challenges these risks present from a central bank perspective. The authors stress that climate change will cause huge systemic risks to materialise, which is why it is essential for central banks to enhance their analytical capacities and address these risks. In closing, they make a compelling case for central banks to engage with their elected governments in matters of climate change mitigation and adaptation policies.

The need for immediate action to reach ‘net zero’ by 2050 cannot be overstated. According to a recent UN report, countries’ latest goals submitted under the Paris Agreement are not ambitious enough.[198] Even the Covid-19 pandemic, which led to the largest annual relative decline in carbon emissions on record and saw emissions reductions in every major economy but China, has brought only temporary relief, and has done so at tremendous cost. While we need a sustained decrease in emissions, according to new data from the International Energy Agency, by December 2020 the world was again emitting more carbon than a year before.[199] This underscores the urgency of structural economic changes to avoid a lasting rebound in emissions.

198 UNFCC (2021).
199 See IEA (2021).

The time to lay the groundwork for an orderly transition to a more sustainable economy and climate-resilient financial system is now. It is essential that the public sector, the real economy, and scientists and researchers all work towards the same goal: putting the global economy on a solid path towards net zero by 2050. Nonetheless, there is no doubt that elected governments have the most powerful tools to incentivise the necessary transition.

Net zero across the value chain

The key question, then, is how to manage the transformation to net zero. Promoting the development and use of emission-free processes and products is an important step towards making net zero a reality across the entire value chain. A crucial prerequisite for this kind of economic transformation is the introduction of a credible carbon price path over the medium to long term. Putting a price on carbon would incentivise demand for lower-carbon products and services while spurring innovation and strengthening corporate efforts to invest in lower-emission production.

The investment required for this transformation could be facilitated further by the mandatory disclosure of climate-related financial risks. To start, disclosing the carbon footprint of individual projects or entire corporations would foster transparency and allow potential investors to better gauge the risks they are taking. The provision of more comprehensive information will thus lead to a reduction in information asymmetries and contribute to the adequate pricing of climate-related risks.

In short, carbon prices as well as disclosures can promote investment in and the development of new technologies, which will cause the cost of reducing emissions to fall. To accelerate this virtuous circle, the public sector can play a supportive role by embracing appropriate policies on both the supply and demand side. On the supply side, broadening the investor base for research and development can contribute to this goal. More specifically, as projects in this field are often subject to a high level of investment uncertainty that may keep private investors away, governments could use public funds to initiate public–private partnerships (PPPs) that would mobilise private sector funds for high-risk, high-reward research. On the demand side, public spending on innovative products and services can provide additional support.

Core tasks of central banks

Central banks are another key public sector player that can take on an important role in global efforts to combat climate change. By preserving price stability, safeguarding financial stability, and supervising financial intermediaries – i.e., by fulfilling their core tasks – they are already setting the foundation for achieving net zero.

Price stability

Transforming the economy and society as a whole will require considerable investment.[200] What long-term investment requires in turn is planning certainty. For public and private investors alike, planning certainty means being able to reliably forecast costs and expected returns. Price stability is key to these considerations, as a high and volatile inflation rates make it more difficult to extract price signals.[201] If gradual shifts in the price of carbon coincide with strong price fluctuations, their signalling effect will largely be lost. In short, by preserving price stability, central banks ensure the effectiveness of price signals and can support the economic changes these incentivise.

Financial stability

The substantial long-term investment needed to transform our economy requires not only reliable information on prices but also stable financial markets. Only a stable and resilient financial system performs best in terms of allocating savings, funding investment, and putting the right price on risks. Climate change-related risks, whether they are physical or transition risks, are themselves a threat to financial stability. This is why central banks need to identify and monitor the magnitude of these risks by covering them as part of their macroprudential supervision activities. Where appropriate and necessary, they also have to assess the need for preventive policies to mitigate systemic risks. The Network for Greening the Financial System (NGFS) helps address this objective by developing climate scenarios, which are key ingredients to macro- and microprudential stress testing.[202]

Banking supervision

We expect banks to play their part, too, and to properly incorporate climate-related financial risks into their risk management frameworks and back them with adequate capital. This will protect their balance sheets and put them in a position to finance transitional projects. To enable banks to get to grips with climate-related financial risks, we have established guidelines urging them to address the impact of climate risks on their business models.[203] This guidance not only clearly outlines supervisors' understanding of a prudent approach to managing climate-related risks, but also seeks to improve industry awareness of and preparedness for managing these risks. And we will engage in a close dialogue with institutions to follow up on their progress. Furthermore, in a reflection of the increasing risk that climate change already poses for banks, the ECB's next supervisory stress test will also focus on climate-related risks. Climate-related stress tests can be an important tool to identify relevant risks and initiate appropriate action.

200 The European Commission anticipates that additional private and public investment of €2.6 trillion will be required between 2021 and 2030, which equates to around 184% of capital expenditure between 2010 and 2019 (see European Commission, 2019).
201 See Phelps et al. (1969).
202 See, for example, NGFS (2020).
203 See ECB (2020a) and BaFin (2019).

Central banks' operational frameworks

We shouldn't expect banks to do something we aren't doing ourselves: central banks ought to be aware of the climate-related risks on their own balance sheets. In response to the pandemic, central banks around the globe have taken unprecedented measures to preserve favourable financing conditions. As a result, monetary policy portfolios make up a large part of their balance sheets, which has amplified the need to understand and assess these risks.

The NGFS recently published a comprehensive report[204] on the implications of climate change for central banks' operational frameworks with a view to providing an analytical framework for central banks globally to assess their monetary policy operations. This report builds on a common understanding that climate change and climate-related risks have an impact on the conduct of monetary policy. It complements previous work by the NGFS from a practical perspective as it reviews, in depth and in detail, possible adjustments in three key areas pertaining to central banks' monetary policy frameworks:

- credit operations;
- collateral policies; and
- asset purchases.

TABLE 3 **SIMPLIFIED COMPARATIVE ASSESSMENT OF THE SELECTED GENERIC OPTIONS UNDER REVIEW**

	CREDIT OPERATIONS			COLLATERAL				ASSET PURCHASES	
	(1) ADJUSTING PRICING TO LENDING BENCHMARK	(2) ADJUSTING PRICING TO COLLATERAL	(3) ADJUSTING COUNTERPARTIES' ELIGIBILITY	(4) HAIRCUT ADJUSTMENT	(5) NEGATIVE SCREENING	(6) POSITIVE SCREENING	(7) ALIGNING COLLATERAL POOLS	(8) TILTING	(9) NEGATIVE SCREENING
CONSEQUENCES FOR MONETARY POLICY EFFECTIVENESS	Minimal	Negative	Strongly negative	Minimal	Negative	Positive	Minimal	Minimal	Negative
CONTRIBUTION TO MITIGATING CLIMATE CHANGE	Strongly positive	Positive	Positive	Positive	Positive	Strongly positive	Strongly positive	Strongly positive	Positive
EFFECTIVENESS AS RISK PROTECTION MEASURE	Minimal	Minimal	Positive	Positive	Positive	Negative	Positive	Positive	Positive
OPERATIONAL FEASIBILITY	Negative	Negative	Minimal	Negative	Minimal	Minimal	Negative	Negative	Minimal

POTENTIAL IMPACT: STRONGLY POSITIVE; POSITIVE; MINIMAL; STRONGLY NEGATIVE; NEGATIVE

Source: NGFS (2021).

204 See NGFS (2021).

The centrepiece of the report is a selection of nine concrete options that would be available to central banks to reflect climate-related risks in their monetary policy frameworks. Importantly, the experts and monetary policy practitioners based their assessment of these nine options on four different criteria: (i) consequences for monetary policy effectiveness; (ii) contributions to mitigating climate change; (iii) effectiveness as risk protection measures; and (iv) operational feasibility (see Table 3).[205]

While the levels of preparedness to reflect climate-related risks may differ from one central bank to the next, the NGFS report offers an operational toolkit for central banks to consider adapting their monetary policy frameworks in line with their respective mandates. The report does not recommend the central banking community to take any particular course of action for the implementation of monetary policy. Each central bank needs to decide for itself how best to reflect climate risks in its operations according to its specific needs and policy context.

Conclusion

The action taken in the near future will be crucial. Governments have rolled out large-scale support programmes to help the global economy recover from the pandemic. This investment will shape the future of our societies and economies. Therefore, it is particularly important not to focus merely on rebuilding the old economy with its inherent climate risks. Instead, all stakeholders need to work hand in hand to transform the entire value chain of the economy. Our common goal is net zero by 2050, and it is crucial that all sectors are on a credible path to decarbonisation.

By fulfilling their core tasks, central banks lay the key groundwork for climate policies to maximise their potential. However, central banks should not leave it at that. They should reflect climate-related financial risks in their operational framework as well. While central banks will face practical and analytical challenges, including data gaps and data quality concerns, adjusting central banks' operational frameworks is feasible. Given the systemic risks that climate change presents for the economic outlook, the financial system, and thus for the conduct of monetary policy, and acknowledging that a lot of work still lies ahead, taking no action is not an option.

5.3 DISCUSSION OF CHAPTER 2, "DO ASSET MANAGERS RESPOND TO NATURAL DISASTERS?", BY ROBERT ECCLES

This is an interesting and useful chapter, albeit a somewhat unusual one for a finance professor to write. As someone trained in sociology with only a smattering of knowledge of finance, it was refreshing to read a chapter I could mostly understand. But as someone who is quite familiar with the world of asset managers, there are some issues I think

205 Interested readers will find a detailed description of the nine options in Table 1 on page 5 of NGFS (2021).

the chapter could explore in more depth. I am not qualified to comment on the authors' arguments about the limitations of hedging and insurance contracts, although I found them useful and informative. Thus, I will focus on those areas where I have more familiarity and would encourage the authors to extend their analysis on these points. I have three main points: (1) the chapter is based on a false premise; (2) the chapter ignores how universal owners are approaching system-level effects; and (3) the chapter needs to take a broader and more informed view about 'corporate activism' in light of the previous two points.

First and to begin, I think this chapter is based on a false premise, one common in the finance academic community, that 'sustainability' (an admittedly ambiguous term, but where the authors do not offer a clear definition of their own) and ESG investing implies giving up some financial return. The false premise is revealed in this paragraph:

> "From the equilibrium perspective, the process of changing preferences for sustainability implies a transition from a 'brown-type' economy to a 'green-type' economy. Interestingly, even though the transition period exhibits a massive upward pricing of green assets, *ultimately the steady state would imply lower expected returns*. This process could sustain the equilibrium in that *investors with a relatively large preference for sustainability would lose to the benefit of investors with a stronger preference for pure returns*. Again, this simple process illustrates why, *from the long-run perspective, 'doing well by doing good' is likely a fallacy*." (italics mine)

This false premise is grounded in an ideological bias. Consider the authors' statement that "an alternative role of asset managers can come from their leadership role in driving social norms. In particular, trading can allow investors to express their ideology." This rather takes my breath away given the fiduciary duty investors have to earn returns for their clients and ultimate beneficiaries. Those doing sustainable investing aren't the ideologues. Rather, the ideologues are those who argue against it, either because of their political orientation (the authors note that Republicans are less likely to engage in sustainable investing than Democrats) and/or because this type of investing doesn't neatly fit into the theory of financial economics and the kind of research top academic journals find acceptable for publication.

Consider the fact that there is a growing body of research showing that taking account of material sustainability issues actually contributes to financial performance.[206] Yet those who hold the ideological bias that somehow 'sustainability' necessarily means lower financial returns simply choose to ignore this research because it doesn't fit their world view. A good example is the recent Department of Labor Ruling[207] regarding ESG investing that was issued in the waning days of the Trump administration. This ruling confounded 'sustainability' with 'non-pecuniary'. Signalling that the Department

206 For a nice overview, see Serafeim (2020).
207 See https://www.dol.gov/newsroom/releases/ebsa/ebsa20201030

of Labor really wasn't interested in the comments they received, the traditional 90-day comment period was reduced to 30 days. Nevertheless, it received 8,737 comment letters, many from professional investors who are putting real money to work for their beneficiaries. Gorte et al. (2020) analysed all of these comment letters and found that 95% were opposed to the ruling. Yet, and not surprisingly, the administration went ahead with their ruling. Under the new Biden administration, the Department of Labor has announced it will not be enforcing it and is looking to undo it.

This bias results in suggesting that this move to sustainable investing "is yet another cyclical movement in social norms and the observed behaviour may simply be short lasting and reflecting more of economic agents' incentive to currently prevailing norms". While it is encouraging to see a chapter on finance recognise the importance of social norms, it is not simply social norms to create "a more sustainable and socially friendly world" that are contributing to the rise of sustainable investing that is nicely documented in the chapter. Outside of the tiny world of classic impact investing (with its strict criteria of intentionality and additionality), which, it should be noted, includes both 'concessionary' (a willingness to sacrifice some financial return) and 'non-concessionary' (earn risk-adjusted returns while also having a positive environmental and/or social impact on the world), sustainable investing is a particular investment strategy. Various taxonomies exist for the different types of sustainable investing but there are essentially these seven that I described in an article with Svetlana Klimenko:[208]

- **Negative/exclusionary screening** (eliminating companies in industries or countries deemed objectionable)
- **Norms-based screening** (eliminating companies that violate some set of norms, such as the Ten Principles of the UN Global Compact)
- **Positive/best-in-class screening** (selecting companies with especially strong ESG performance)
- **Sustainability-themed investing** (such as in a fund focused on access to clean water or renewable energy)
- **ESG integration** (including ESG factors in fundamental analysis)
- **Active ownership** (engaging deeply with portfolio companies)
- **Impact investing** (looking for companies that make a positive impact on an ESG issue while still earning a market return)

208 Eccles and Klimenko (2019).

ESG integration is the most rapidly growing strategy. In it, the investor factors in a company's performance on the material ESG issues for its sector and strategy, just as it factors in traditional financial factors as in the Fama–French five-factor model. The focus of sustainable investing is not about making the world a better place per se, although there is this benefit, but ensuring that a company is well-positioned to avoid or at least mitigate natural disasters. Safeguarding returns goes hand-in-hand with broader social benefits. Through ESG integration, all investing is becoming sustainable investing.

Not surprisingly, the authors argue that "[i]n its simplest form, asset management is an application of two seminal theories, the portfolio theory by Markowitz and the Capital Asset Pricing Model by Sharpe". The unit of analysis for ESG integration is the company or portfolio and so it fits within these two theories, although they must be extended to new variables. However, and this is my second point, the chapter completely ignores the fact that large asset owners and asset managers have increasingly shifting their focus to system-level risks, a level of analysis beyond individual stocks and portfolios. Two books are coming out in the next month about exactly this point.[209] The basic idea is that so-called 'universal owners' who hold very large positions and have a long-term perspective, such as large passive asset managers and asset owners, cannot diversify away from system-level risks like climate change or income inequality. They aren't chasing alpha; they just want to get a decent beta. If the state of the world is such that they cannot do so, they can't meet the needs of their clients and ultimate beneficiaries.

In "Universal Ownership in the Age of the Anthropocene",[210] Ellen Quigley explains that "[u]niversal owners such as pension funds, insurance companies, university endowments, and sovereign wealth funds have an interest in the long-term health of the financial system as a whole … These asset owners cannot diversify away from systemic risks such as climate change, inequality, and pandemics, and can only mitigate whole-system threats by effecting change in the real economy." She contrasts this with the portfolio-level focus of sustainable investing, which is focused on adopting an environmental or social lens to mitigate risk from the real economy "but which has little to no impact on the real economy from an asset allocation perspective". In contrast, the goal of universal owners is to mitigate system-level risks by changing the nature of the real economy. A universal owner will not favour an investment that generates a positive alpha if the externalities of its products and services are having a substantially negative impact on the real economy, since this makes it hard for the investor to earn a decent beta. The Shareholder Commons[211] is working to develop strategies for universal owners to better address system-level issues.

209 Lukomnik and Hawley (2021) and Burckart and Lydenberg (2021).
210 Quigley (2019).
211 See https://theshareholdercommons.com/.

The authors ignore the role of asset managers in dealing with systemic risks. Instead, they first explore private insurance as an option, but conclude it isn't a viable one. They suggest that this is a role for the public sector and conclude that "in the context of largely nonhedgeable risks, the system that complements the private sector with the engagement of the public sector may allow for a better resilience of the social welfare". But this is to deny the agency investors have in dealing with system-level risks and the self-interest they have in doing so.

Third, the authors in include some discussion about corporate activism, such as "voting campaigns focused either on direct corporate actions or changes in corporate leadership". Once again, the false premise and ideological bias of the authors is revealed by framing activism as seeking "the adoption of socially friendly corporate policies" such as "the reduction in greenhouse gas production" or organising "minority groups around important social agenda". The authors also note that activism has "proved particularly helpful in forcing disclosure of climate-related information".

Setting aside the fact that, in practice, the term "activism" is more often used as a particular type of engagement, investors perform this activity to improve financial returns, not to create a social benefit at their expense. Engagement takes place at both the stock and portfolio level as well as the system level. In the former, engagement is used to improve a company's sustainability performance in order to improve its financial performance. An example of the former is the "Reenergize ExxonMobil" campaign.[212] This campaign is solely based on an economic argument. The company has failed to recognise the need to shift its business model as the real economy moves away from oil and gas, and hence it's financial returns have been abysmal. The company is also famous for its obdurate attitude regarding its shareholders and lack of transparency. This campaign uses the classic techniques of hedge fund activism by proposing a slate of four alternative directors with climate experience. It is an example of the idea of 'activist stewardship', which I am working on with CalSTRS.[213]

Engagement can also take place at the system level. Consider BlackRock's requirement that all if its portfolio companies start reporting according to the framework of the Task Force on Climate-related Financial Disclosures. Another example is Climate Action 100+,[214] a coalition of 575 investors with \$54 trillion in assets under management. This group is focused on engaging with a global set of 167 companies that account for around 85% of industrial GHG emissions. These companies have been evaluated in terms of commitments to net zero by 2050, targets, and disclosures of plans and progress.[215] It is inconceivable that a group this large is looking to sacrifice financial returns simply to produce the social good of a cleaner environment.

212 See Eccles and Mayer (2021).
213 Eccles et al. (2021).
214 See www.climateaction100.org/.
215 See www.climateaction100.org/progress/net-zero-company-benchmark/.

Finally, it should be noted that while disclosure has a key role to play in engagement at both the company and system level, it is not an end in itself. Investors use disclosure, or the lack thereof, as the basis for engagement discussions. They also want targets against which disclosures are made.

The empirical analysis in this chapter is excellent, but I would encourage the authors to reconsider its overall framing in light of these three points.

5.4 DISCUSSION OF CHAPTER 2, "DO ASSET MANAGERS RESPOND TO NATURAL DISASTERS?", BY STEFANO GIGLIO

The chapter offers a comprehensive overview of the role that asset managers play in responding to climate risk and natural disasters. Asset managers are important global actors within the financial system, not least because of the large amount of capital that they allocate (about $100 trillion globally, as the chapter reports). Only a small fraction of this amount is currently directly allocated to ESG investments, but the recent rapid growth of sustainable investments signals an increased interest from these investors to climate change issues.

The chapter covers a wide range of topics and ideas. In this discussion, I first organise the chapter's main points around four questions. Then, I expand on a few ideas discussed in the chapter, and try and identify areas where I think further research is particularly needed.

The first question the chapter asks is: what is special about the asset management sector, when thinking about climate risks? Beyond the size of the sector, mentioned above, the key feature is the well-known agency relation between managers and investors. The potential misalignment of incentives in this relationship may lead asset managers to take actions that do not necessarily fully reflect the preferences of the funds' investors (for example, their preferences for risk exposures or ESG investments). As an example that is particularly relevant for climate risks, if managers focus on short-term risks they may not react properly to climate risks, which are inherently longer-duration risks.

Second, the chapter explores the question: what is special about climate risk, as opposed to any other risks that investors already manage? The chapter highlights many features of climate risk that make it harder to manage than most other risks investors typically deal with. These include the large amount of uncertainty about the nature and evolution of climate risk (the physical processes, the relations with the economic processes, and the endogenous response of the economy's agents to adapt and mitigate the risks); the non-stationarity of the climate change problem and the limited amount of data available to investors to understand how to best deal with it; and the incompleteness of financial markets, reflected in the relative scarcity of instruments available to hedge these risks.

The third question the chapter addresses is whether climate risk is priced in financial markets. This question plays a crucial role in assessing how the private sector manages climate risk. We can only hope to use asset markets to learn about climate risks, and to build portfolios to help manage and transfer those risks, if asset prices reflect climate risks in the first place. The pricing of climate risk would be a sign that investors are aware of the risks associated with climate change and anticipate the corresponding effects on the cash flows of companies. An emerging literature has explored this topic, including recent papers by the authors of this chapter[216] and a recent review in Giglio et al. (2020).

Lastly, the chapter examines two distinct roles that asset managers may play in the financial system to respond to climate risks: *mitigating* climate change and *adapting* to climate change. On the mitigation front, the main tools available to asset managers are capital reallocation (e.g., divestment), and activism (e.g., voting and pressure on the invested companies' actions). On the adaptation front, asset managers may contribute to the stability of the system by participating in hedging and risk transfer, contributing to more efficient risk-sharing of climate risks in the economy.

The next sections offer some thoughts on specific themes, with a focus on identifying areas where further research is particularly needed.

The drivers of change

The chapter documents the recent rapid increase in sustainable investment in the United States and, even more strongly, in Europe. What has driven this change? It is useful to distinguish among three complementary reasons. First, it could reflect a change in what the chapter refers to as 'non-pecuniary' motives – effectively, a pure preference for sustainable assets, that is not directly related to the risk-return profile of the investment. Second, it could reflect a 'hedging' motive – investments in certain (e.g., green) companies may offer hedging benefits against either physical or transition risks, and therefore play a direct role within standard portfolio risk management. Third, it could reflect pressure from regulators, either from current regulation or from anticipated regulatory changes along the transition to a more sustainable economy (e.g., an anticipated increase in carbon taxation).

While all three of these motives may push in the same direction, they are not perfect substitutes and, in fact, some may lead to more sustainable resilience to climate risks in the long run than others. A change in the public's non-pecuniary preferences for sustainable investment can be a powerful driver of change in the way assets are allocated and on the cost of capital. However, it is well known that investor preferences can exhibit transitory fluctuations, and investor enthusiasm for sustainable investments may be dampened in the future for a variety of reasons. In fact, the issue of climate change has been widely discussed in previous decades – but only recently has investor behaviour

216 See, for example, Bolton and Kacperczyk (2020a,b).

started to reflect it at a much larger scale. To be clear, there are good reasons to believe that 'this time is different': since climate risks are likely to become even more salient going forward, it is unlikely that investor attention will vanish entirely. However, it is not unreasonable that investors' attitudes might change in the future, for example if long-run returns from green investments are sufficiently low (and, as discussed in the chapter, there are good reasons to expect this).

An alternative perspective is that climate change is one of many risks to be hedged, therefore bringing the issue within standard risk management frameworks. Compared to relying on the non-pecuniary preferences of investors, this hedging perspective may have one important long-term advantage: low long-term returns can be more easily contextualised and interpreted as reflecting the cost of buying climate insurance. Ultimately, this may be the key to achieve long-term reallocation of capital toward sustainable investments, even in the face of lower equilibrium returns. Among the potential externalities of asset managers for the rest of the economy – discussed in the chapter – we can include educating investors on the importance of viewing sustainable investments as hedges against climate risks.

Understanding the benefits and costs of these motivations (as well as comparing them with the costs and benefits of regulatory intervention) is important when thinking about the role of asset managers in dealing with climate risks. Unfortunately, at the moment, it is hard to obtain a quantitative sense of investors' perceptions of the trade-off between returns and sustainable investment, and of the role of non-pecuniary versus hedging preferences. This is a gap that could be filled by future research: empirically, by surveying investors, and studying how their preferences evolve over time as we learn more about climate risks; and theoretically, by studying the theoretical properties of these different motivations for sustainable investment and by exploring the welfare implications.[217]

Hedging climate risks

A central point tackled in the chapter is the ability of financial participants to hedge and share climate risks. Specifically, the chapter has a nice discussion of the various aspects of this risk that make it inherently more difficult to hedge.

I want to add two thoughts to this discussion. First, the chapter may underestimate the availability of opportunities to hedge climate risks. While climate change is a global phenomenon, there are large disparities across the world in both the potential damages from climate change, and the ability to bear climate risks. As an example of the former, consider different geographic locations even within the same country (e.g., within the United States). Mountain areas are affected very differently by climate change than coastal areas. In fact, some areas might actually benefit from climate change. For example, Murfin and Spiegel (2020) document that relative sea levels might actually

217 See, for example, Pastor et al. (2020).

decrease along part of the US coast as a consequence of climate change; and farming in some regions might be improved due to changing temperatures. As an example of the latter, many developing countries are known to be especially exposed to climate damages, for instance because they are at a low elevation or lie in hurricane zones. Developed countries might be relatively better able to bear and adapt to these damages. Welfare gains may therefore be achieved by transferring climate risk from developing to developed countries.

Second, to the extent that there may be welfare gains from hedging and sharing climate risks, the next fundamental question becomes to what extent financial markets provide suitable instruments for doing so, at a level and scale required by the size of climate risks and damages. Current instruments available to hedge climate risks (e.g., reinsurance, catastrophe bonds and weather derivatives) are somewhat limited, for example because they only provide a way to hedge a small subset of climate risks. It is possible to try and hedge climate risks without using specialised instruments (e.g., using only equities)[218] but, as recent research has pointed out, doing so with indirect instruments like equities only offers partial insurance. Going forward, it is fundamental that the private sector (potentially together with governments) develop better financial instruments and markets that allow investors across the world to share and transfer climate risks.

Looking to future research, the availability of detailed geographic climate data, together with models of climate evolution and asset prices, can help researchers provide quantitative answers both to the opportunities for welfare gains from climate risk sharing, and to the question of how best to design and price climate-hedging instruments.

Is climate risk priced in asset markets?

Understanding whether climate risk is *priced* in asset markets is fundamental both for interpreting the financial response to climate risks and for building hedge portfolios. Expanding on the nice discussion in the chapter, I would like to emphasise that there are multiple aspects to whether climate risk is priced, and it is important to distinguish them from one another.

One aspect is whether asset prices reflect information about firms' exposures to climate risk and damages. For example, when information reveals that a firm pollutes more than previously anticipated, do prices react? Do prices of polluting firms move in response to changes in policy that affect transition risk? These questions related to comovement (beta) of asset prices with respect to climate risks; a recent literature has explored them

218 As in Engle et al. (2020).

extensively in various asset classes.[219] A second aspect is whether investors require a risk premium for exposure to climate risks, and quantitatively, how large that premium is. These questions related to compensation for bearing climate risk, as opposed to risk exposures.

Each of these two aspects captures a different dimension of the way climate risks are reflected in asset markets. In addition to making note of this distinction, I want to point out its practical importance. Whether climate risks are reflected in asset prices (the 'covariance' interpretation) can be assessed in a short sample of data, such as the one we typically have available in relation to climate change. Estimating risk premia, on the other hand, is much harder in short time series. When we observe a portfolio having, for example, a high return over a short time period (e.g., five to ten years), it is difficult to distinguish whether that return truly corresponds to a high risk premium accumulated during those years, or if it reflects a realisation of a positive, unexpected shock to the firm over that period. Only with relatively long time series can the two be distinguished, which should make us take care when interpreting estimated risk premia from climate-hedging portfolios over the short time series we have available.

How do managers behave?

Understanding how asset managers contribute to the overall resilience of the financial sector to climate risks would be easier if we had a better sense of managers' beliefs about climate risks, and their behaviour with respect to these risks. Unfortunately, we know little about either. Only very recently have researchers started to study how managers actually incorporate information about climate exposures of firms into their portfolios and how climate risks affect their hedging decisions.[220] There are many fruitful directions that can be pursued in future research. For example, surveys of asset managers can directly reveal how they perceive the risks and the risk-return trade-offs. In addition, the reactions of managers to their beliefs can be studied by linking surveys with (in some cases, publicly available) data on their portfolio allocations.

Concluding remarks

This excellent chapter summarises well the many aspects of the role played by asset managers in dealing with climate risks. One concluding thought – that goes beyond the specific focus of this chapter on asset managers – is that it is important to think about the behaviour of asset managers together with the behaviour of the other agents in the economy, and especially the public sector (covered in the other chapters of this report). It is yet to be determined quantitatively how far actions by the private sector alone (like disinvestment or activism) can go in addressing climate risks. But it is likely that public interventions will be strongly needed even if the current interest in sustainable investing

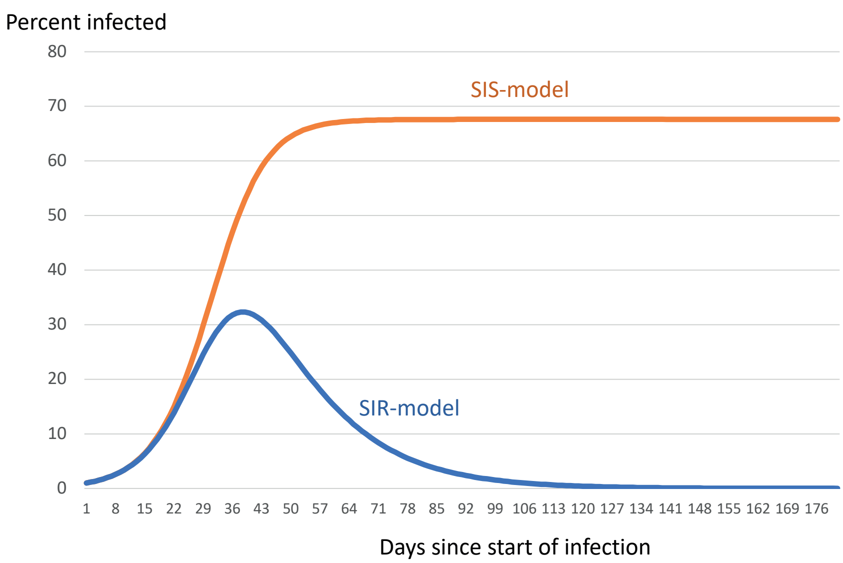
219 For example, Giglio et al. (2021) and Engle et al. (2020).
220 Two recent papers in this direction are Alok et al. (2020) and Bolton and Kacperczyk (2020d).

from private investors persists. In addition, the public sector can directly help the private sector achieve better outcomes. For example, regulation can help better align the incentives of asset managers to mitigate climate change, it can facilitate the information flow from firms to asset managers (for instance, by standardising disclosures), and it can help coordinate the creation and functioning of specialised markets for hedging climate risks. A coordinated approach between the various players (both between the private and public sectors within a country and across countries) will likely be needed to improve the resilience of the financial sector to climate risks at a global scale.

5.5 DISCUSSION OF CHAPTER 3, "MITIGATING DISASTER RISKS TO THE FINANCIAL SYSTEM", BY JOHN HASSLER

The first part of the chapter analyses the Covid-19 pandemic. A so-called SIS model is used, where individuals transit back and forth between being susceptible and infected without ever being immune; the only absorbing state is death. This contrasts with the standard model for virus epidemics, the SIR model, where infected individuals recover and become immune unless they die. The SIS model is suitable for bacterial infections, where recovery does not lead to immunity, but is in principle not suitable for virus infections. This is because the dynamics are quite different, as illustrated by Figure 15. The key difference is that in an SIR model, the epidemic dies out of itself in lack of susceptible individuals. Thus, in the long run, the number of infected is zero in the SIR model while it plateaus in the SIS model. Assuming the same transmission mechanism, the initial dynamics are, however, similar in the two cases.

FIGURE 15 **DYNAMICS OF DETERMINISTIC SIS AND SIR MODEL**



Given that a central purpose of the exercise is to analyse how expectations about the launch of a vaccine affect the stock market, it does not seem innocuous to use a model with quite different predictions about future infection rates than the more appropriate SIR model. In particular, in an SIS model only a vaccine can stop the pandemic, while in a SIR model the development of immunity also can stop it. A common view in the beginning of the Covid-19 pandemic was that immunity would occur long before a vaccine arrives. Over time, this view was reversed towards an expectation that a vaccine is going to do it.

Many other things also changed over the first half year or so of the pandemic. For example, it turned out that the important sectors in the economy could continue operating despite a substantial share of the work force working from home. The fast recovery of global supply chains also came as a surprise that affected future earnings expectations and firm values.

In epidemiological models, the number of contacts an infected individual has with other individuals and how large the risk is that such contacts transmit the virus are exogenous parameters. In reality, these parameters change, not least because of precautionary measures, both voluntary and imposed by government regulation. In the chapter, such variation is introduced by assuming that the transmission rate, β, follows a random walk. As economists, we would like to endogenise this variation. A reasonable mechanism would be one where individuals and governments purposefully make choices that reduce the risk of becoming infected when that risk is perceived to be high. This would cause a feedback that, under some circumstances, can stabilise the reproduction number. When risk is high, the incentive to change behaviour to reduce that risk is higher and vice-versa. Although such an endogenisation may be outside the scope of the chapter, a discussion about the realism of the random walk assumption would have been valuable.

The second part of the chapter is on climate change and climate damages. Also here, I would like to argue that the model choice is not optimal. It is assumed that the key climate externality is an underinvestment in mitigation investments, not emissions. A more standard model would be built on the assumption that emissions are the externality. I am not convinced that the model choice is innocuous. Specifically, the model is constructed such that aggregate mitigation investment is the key variable to affect by policy. It is tempting to interpret this as green investments. Doing that may lead policy down the wrong path. This is because green investments are not likely to reduce fossil investments one-for-one. Rather, green investments may increase the use of green energy while not being a good enough substitute for fossil energy to sufficiently reduce the latter. Then, the effect of green investments is mostly to increase overall energy consumption. Whether this would happen depends on the aggregate elasticity of substitution between green and fossil industry. It is an open issue how large this elasticity is, but there is at least not consistent evidence that it is so high as to imply a large reduction in fossil energy use when green energy becomes cheaper. This issue becomes more important if the international dimension is taken into account. An increase in mitigation investments in the West may not reduce fossil emissions in China and India by much.

I am also sceptical about the way climate damages are calibrated. The key source for the calibration is Burke et al. (2015), who uses time variation in the average yearly temperature to estimate the effect of climate change on economic growth. Specifically, the following panel regression is run:

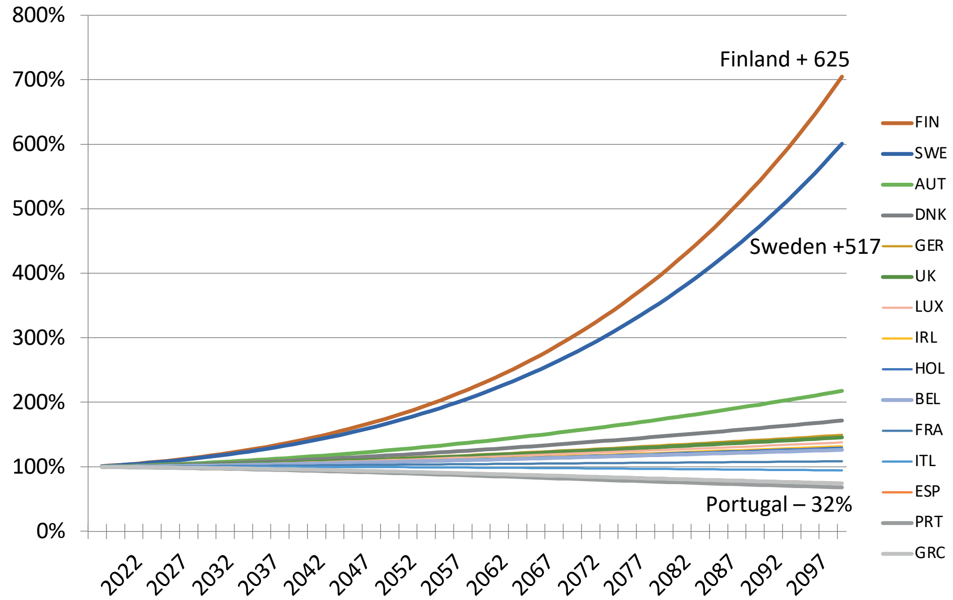
$$g_{i,t} = \beta_1 T_{i,t} + \beta_2 T^2_{i,t} + \mu_i + \tau_t$$

where $g_{i,t}$ is the yearly growth rate in country i in period t, $T_{i,t}$ is the yearly average temperature in country i, μ_i is a country fixed effect and τ_t is a common trend. The estimates of the common global coefficients imply that $\beta_1 > 0$ and $\beta_2 < 0$. Thus, an increase in the temperature increases growth for countries with a cold climate and reduces it for a sufficiently warm national climate. It is then assumed that these temporal relations also represent the effects on growth of permanent changes in the temperature resulting from climate change.

Using the parameters from Burke et al. (2015), it is assumed that the average global growth rate of GDP falls by 0.3% per year due to climate damages. This comes in the form of a global weather-related climate disaster that destroys an average of 14% of capital stock. Using a capital output ratio of three, this means a shock of 42% of GDP. The shock hits the economy with a Poison arrival rate of 1/7 per year. This is quantitatively (i.e., the size of the effect) and qualitatively (i.e. everything comes in the form of a common global shock) questionable.

To illustrate that the effect is built on individual country effects that appear unreasonable, I used the estimated β-coefficients to predict the effect of climate change on the growth rate of EU countries. I used a scenario where the global mean temperature increases by 2.5°C towards the end of the current century. To predict the changes in national temperatures, I used statistical downscaling from an ensemble of climate simulations assuming that the national temperature is represented by the temperature in the national capital. The consequences of climate change for GDP in the EU countries relative to no increase at all in the temperature are depicted in Figure 16.

FIGURE 16 **EFFECTS OF 2.5°C INCREASE IN GLOBAL MEAN TEMPERATURE ON GDP PER CAPITA IN EU15**

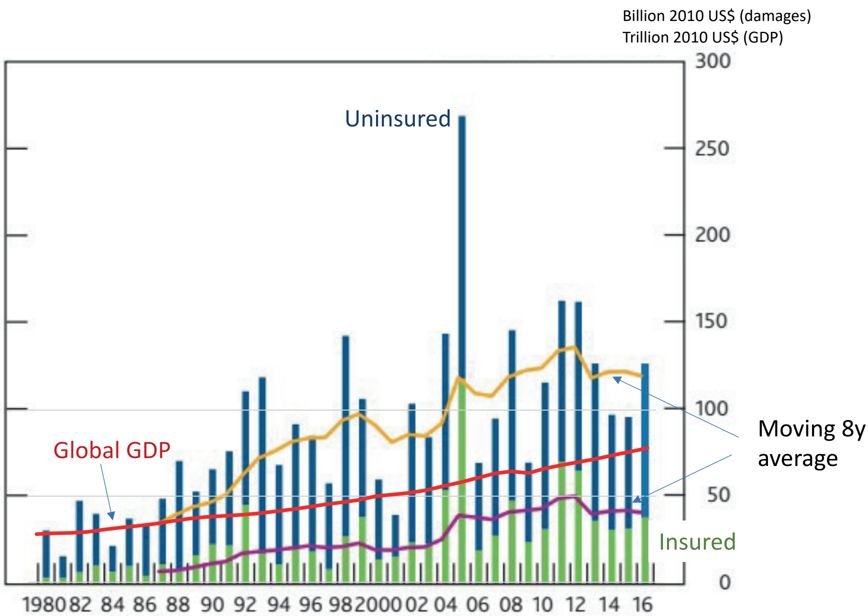


We see in the figure that the prediction is that the GDPs of EU countries will diverge at an unseen rate. In particular, Sweden and Finland will see climate change increase their GDP by five and six times, while some other countries see substantial negative effects. These results from individual countries cast substantial doubt on the aggregate effects estimated in Burke et al. (2015). The average of national effects that individually seem unreasonable should not be trusted, even if the average itself does not appear unreasonable. In my view, the problem with the approach is that high-frequency temporal variation in temperature cannot simply be assumed to be informative about the long-term consequences of climate change.

The assumption that the effect of climate change comes in the form of an extremely large global weather catastrophe occurring, on average, every seventh year is also problematic. That climate change is likely to increase weather-related damages is certainly reasonable, but the size of the shock is orders of magnitude larger than other estimates and appears highly unlikely.

In Figure 17, we see that weather-related damages are in the order of a tenth of a percent of GDP, which is at least two orders of magnitude smaller than the ones assumed here. Damages are increasing, but there is evidence that this is largely due to growth and migration to costal and urban areas.[221] One can of course not rule out that damages will increase, and also increase very much due to climate change, but it does not seem to be in the data yet. Consequently, the approach taken here, where current realizations of weather-related damages on growth are extrapolated seem unfounded.

FIGURE 17 **REAL WEATHER-RELATED LOSSES WORLDWIDE AND GDP**



Source: Bank of England Quarterly Bulletin 2017:2 and World Bank.

Conclusion

The epidemic model used in the chapter is built on a model that is not suitable to describe the dynamics of virus transmission. This, and the fact that many other factors drive variation in stock market prices, make it difficult to assess how relevant the results are for quantifying the effect of vaccine arrival.

The climate change model is based on the idea that the market failure is due to an overly low aggregate level of mitigation investment, rather than emissions of greenhouse gases. This risks focusing policy advice on stimulating green investments, for example through green investment funds. There are at least two reasons to believe that such a strategy could be ineffective. First, a focus on green energy-related investments may increase

221 Bank of England (2017).

the use of green energy while not reducing fossil energy by much. Second, aggregate mitigation investment can be a bad measure of how much aggregate emissions fall, since there are strongly falling marginal effects of emission reductions implying that the distribution of efforts is important.

The parametrisation of climate damages is also quite extreme and much higher than bottom-up estimates as reported, for example, by the IPPC and the Peseta project, where damages are in the order of a few percent of GDP. While these estimates may miss many effects and thus be severe underestimates, it is important to make a distinction between damages that have strong empirical support and damages that are more speculative.

5.6 DISCUSSION OF CHAPTER 3, "MITIGATING DISASTER RISKS TO THE FINANCIAL SYSTEM", BY ROBERT LITTERMAN

Chapter 3 recognises several parallels between the Covid-19 pandemic and climate change:

1. that they are global risk management problems due in large part to externalities not being internalised, arguably because of a lack of adequate government intervention;
2. that there is insufficient mitigation, which is likely to impact market valuations through damages and changes in discounting; and
3. that the management of these types of risks requires an expensive and difficult to coordinate global response.

And while recognising differences – for example, the importance of the vaccine in addressing Covid-19 and the lack of an obvious analogue with respect to climate, and the fact that climate impacts both labour and capital whereas the pandemic hit only labour – the chapter nonetheless tries to draw lessons using quantitative models and analogous mechanisms. In fact, however, there is little attempt to link the parameters or mechanisms of the model of Covid-19 with those of climate change and any lessons are made through loose analogies.

In the end, the bottom-line conclusion of the chapter is that the potential incentives for firms to mitigate greenhouse gas pollution through sustainable finance mandates are an order of magnitude too small. While the conclusion is plausible, neither the parallels with the pandemic, nor the general equilibrium model calibration exercise used to demonstrate this, are convincing.

The chapter defines the "cost-of-capital wedge" between a sustainable firm and a non-sustainable firm as "the sustainable firm's mitigation spending divided by its market valuation," and asserts that "an optimally designed mandate can in theory substitute for a capital tax".[222]

I would question whether mandates could possibly be effective because, in equilibrium, if one set of lenders pulls out of a market, any increase in return per unit of risk will immediately attract other investors. If a mining company sells its coal business to increase its 'sustainability', the business will still operate and emissions will not have changed.

The chapter notes the importance of vaccines, a public good developed and paid for by governments around the world, but then focuses on the non-pharmaceutical interventions "such as social distancing or testing" as the parallel for climate mitigation taken by firms. Unfortunately, though, the calibration does not try to identify how large the private benefits to firms of such interventions are relative to the socially optimal amount of such interventions, if the public good benefits were to be internalised. Though not addressed, that difference between public and private benefits would seem to be at the heart of the investigation later in the chapter of the inadequacy of attempts to use sustainable finance to cause firms to mitigate climate optimally.

The climate calibration itself starts with an estimate of a negative 24% impact of unmitigated climate damages on GDP per capita in 2100, derived from a "widely used projection" which fits a non-linear response of GDP to average temperature. While I do not have a better approach to suggest for estimating the mean impact of unmitigated climate change on GDP in 2100, I would observe that there is wide disagreement about this estimate in the economics fraternity.

Stanford economist John Cochrane, for example, recently testified to the United States Senate Committee on Banking, Housing, and Urban Affairs:[223]

> *"...the worst-case economic scenarios for climate are 7 percent to 10 percent of GDP in a hundred years, a tenth of a percent per year. And that is the worst case...over the horizon that we can think about things, this is a small risk to the U.S. economic and financial system. Sorry, but that is a fact."*

I would have emphasised the uncertainty of any estimate of the damage distribution in 2120 rather than claiming I know something definitive about it, but I would nonetheless agree with Cochrane that we need to worry about a plausible worst case from the full range of potential outcomes – not the central case, as is the basis for this chapter's 30-basis point expected annualised negative impact on growth. Model uncertainty, which here is

222 Hong et al. (2021).
223 See www.banking.senate.gov/hearings/21st-century-economy-protecting-the-financial-system-from-risks-associated-with-climate-change.

immense, clearly increases the thickness of the tail of potential outcomes. Thus, I find Cochrane's confidence in his 10-basis point worst case estimate implausible, but I also find this chapter's focus on the 30-basis point expected value incomplete.

In any case, the negative 30-basis point impact on expected growth is then converted into a Poisson process with a disaster occurring on average every seven years and with a mean impact on output of 14%. Given this damage process, the model investigates whether spending incentivised by sustainable mandates can protect the economy from the effects of disasters.

But firms potentially spend on two types of climate risk management:

1. firm-specific risk, and
2. systemic risk.

Spending on corporate-specific risk is the cost of buying insurance against climate disasters, and economists would expect firms to purchase a privately optimal amount in equilibrium. Thus, an issue I would have liked to see confronted here is how much of needed systemic risk mitigation, as opposed to firm-specific risk mitigation, can be expected to a motivated by "sustainable finance mandates", which "are meant to incentivize companies to mitigate the effects of climate change".

Consider the actions highlighted in this chapter as part of sustainable finance:

1. passive screens,
2. capital market boycotts,
3. bank and central bank sustainable finance mandates in corporate debt markets, and
4. spending to mitigate a variety of climate-related disasters.

The "efficiency" of mitigation technology is calibrated by assuming that spending 100% of revenue would lead to a 90% reduction in climate-related damages. It is not clear how much of that reduction, however, is firm-specific and how much is systemic risk reduction through the firm's reduction in its greenhouse gas emissions.

It is not obvious, for example, how any of the four actions listed above could help an oil company to reduce emissions created by private automobiles using its product – i.e., gasoline. It would have been nice to see more discussion of how sustainable finance mandates might be better structured to focus on systemic risk.

What will certainly lead to aggregate reductions in greenhouse gas emissions are marginal incentives to reduce emissions such as provided by a variety of direct government policies including carbon taxes, emissions trading systems, fossil fuel taxes and (negatively) subsidies, renewable portfolio standards, low carbon fuel standards, and feed-in-tariffs.

Although not considered in this chapter, there is ample evidence that such incentives are highly effective at reducing the carbon intensity of economic output. Kepos Capital,[224] for example, has computed marginal incentives to reduce emissions for 25 high-emitting countries from 2008 through 2019. The World Bank provides estimates of carbon intensity[225] for the same years. We show evidence below that there is a negative relationship between carbon intensity and carbon prices across countries, and a strong reduction of carbon intensity over time associated with higher prices.

TABLE 4 **KEPOS COMPREHENSIVE CARBON PRICES AND WORLD BANK MEASURES OF CARBON INTENSITY IN KG PER PPP $ OF GDP**

	Kepos Carbon Price		World Bank Carbon Intensity		Percentage change in intensity
	2008	2019	2008	2019	
Argentina	25	-4	0.27	0.23	-0.16
Australia	19	25	0.49	0.33	-0.32
Brazil	-14	-11	0.15	0.16	0.03
Canada	17	45	0.42	0.33	-0.23
China	0	7	0.75	0.53	-0.30
Czech Republic	29	45	0.40	0.27	-0.33
France	62	103	0.16	0.11	-0.30
Germany	41	72	0.25	0.18	-0.30
India	0	13	0.36	0.31	-0.13
Indonesia	-34	-11	0.25	0.21	-0.18
Iran	-129	-128	0.46	0.59	0.29
Italy	62	68	0.21	0.15	-0.32
Japan	34	33	0.27	0.22	-0.18
Mexico	-14	11	0.30	0.20	-0.32
Netherlands	37	55	0.23	0.19	-0.18
Russia	0	-6	0.60	0.49	-0.18
Saudi Arabia	-105	-50	0.32	0.38	0.20
South Africa	13	12	0.86	0.67	-0.21
South Korea	19	36	0.35	0.31	-0.12
Spain	35	61	0.22	0.14	-0.34
Turkey	32	22	0.25	0.18	-0.29
UK	58	87	0.23	0.13	-0.43
US	5	18	0.38	0.27	-0.30
Belgium	25	93	0.26	0.18	-0.32
Poland	18	42	0.45	0.28	-0.38

224 See www.carbonbarometer.com/#/.
225 See https://data.worldbank.org/indicator/EN.ATM.CO2E.PP.GD.

FIGURE 18 **CARBON INTENSITY AS A FUNCTION OF CARBON PRICE**

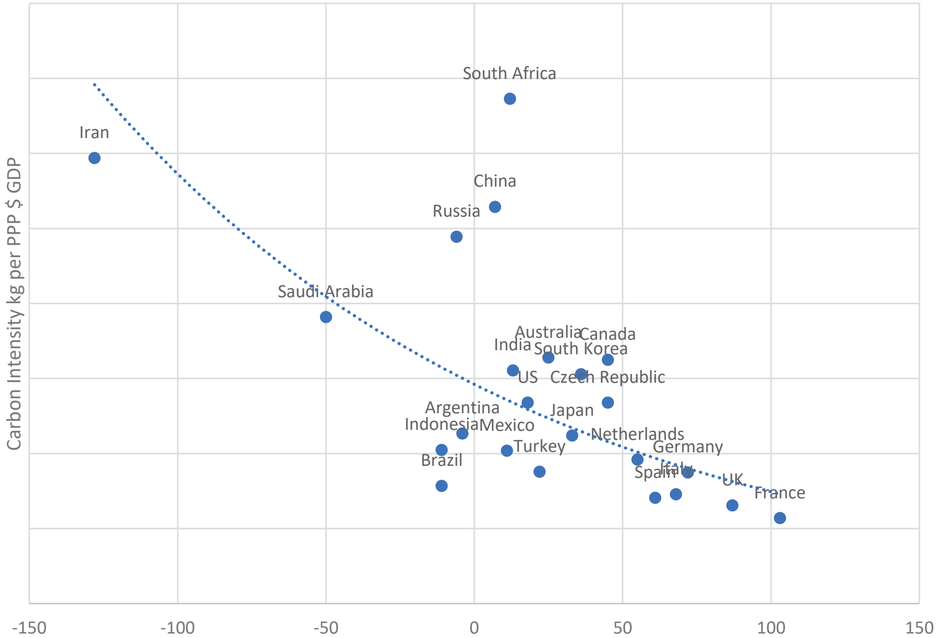
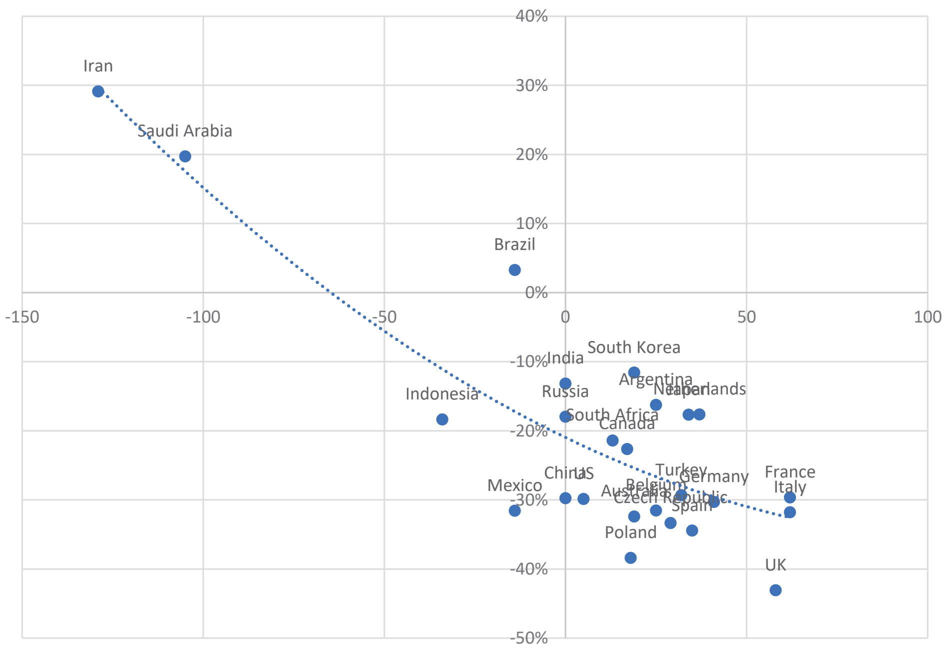


FIGURE 19 **PERCENTAGE CHANGE IN CARBON INTENSITY AS A FUNCTION OF THE BEGINNING OF PERIOD PRICE**



References

Abatzoglou, J.T. and A.P. Williams (2016), "Impact of anthropogenic climate change on wildfire across western US forests", *Proceedings of the National Academy of Sciences* 113(42): 11770-11775.

Abel, G., M. Brottrager, J. Crespo Cuaresma, and R. Muttarak (2019), "Climate, conflict and forced migration", *Global Environmental Change* 54: 239–249.

Allen, T., S. Dees, J. Boissinot, M. Caicedo, V. Chouard, L. Clerc, A. De Gaye, A. Devulder, S. Diot, N. Lisack, F. Pegoraro, M. Rabaté, R. Svartzman, and L. Vernet (2020), "Climate-related scenarios for financial stability assessment: An application to France", Working Paper Banque de France, no. 774.

Alok, S., N. Kumar, and R. Wermers (2020), "Do fund managers misestimate climatic disaster risk?", *Review of Financial Studies* 33: 1146-1183.

Anderson, R.M. and R.M. May (1992), *Infectious Diseases of Humans: Dynamics and Control*, Oxford University Press.

Andersson, M., P. Bolton, and F. Samama (2016), "Hedging climate risk", *Financial Analysts Journal* 72(3): 13-32.

Arnold, R. D. and J.P. Wade (2015), "A definition of systems thinking: A systems approach", *Procedia Computer Science* 44: 669–678 (https://doi.org/10.1016/j.procs.2015.03.050).

Auffhammer, M., S.M. Hsiang, W. Schlenker, and A. Sobel (2013), "Using weather data and climate model output in economic analyses of climate change", *Review of Environmental Economics and Policy* 7(2): 181-198.

Azar, J., M. Duro, I. Kadach, and G. Ormazabal (2020), "The Big Three and Corporate Carbon Emissions Around the World", ECGI Finance Working Paper 715 (forthcoming in *Journal of Financial Economics*).

BaFin (2019), "Guidance Notice on Dealing with Sustainability Risks" (www.bafin.de/SharedDocs/Downloads/EN/Merkblatt/dl_mb_umgang_mit_nachhaltigkeitsrisiken_en.html).

Bailey, N.T. (1975), *The Mathematical Theory of Infectious Diseases and its Applications*, Oxford University Press.

Bamber, J. L., M. Oppenheimer, R.E. Kopp, W.P. Aspinall, and R.M. Cooke (2019), "Ice sheet contributions to future sea-level rise from structured expert judgment," *Proceedings of the National Academy of Sciences of the United States of America* 116(23): 11195–11200.

Bank of England (2017), "Recent economic and financial developments: Markets and operations", *Quarterly Bulletin* 2017:2 (www.bankofengland.co.uk/-/media/boe/files/quarterly-bulletin/2017/markets-and-operations-2017-q2).

Bank of England (2019), *The 2021 biennial exploratory scenario on the financial risks from climate change.*

Bansal, R. and A. Yaron (2004), "Risks for the long run: A potential resolution of asset pricing puzzles", *Journal of Finance* 59(4): 1481-1509.

Barnett, M., W. Brock, and L.P. Hansen (2020a), "Pricing uncertainty induced by climate change", *Review of Financial Studies* 33(3): 1024–1066.

Barnett, M., W. Brock, and L.P. Hansen (2020b), "How should climate change uncertainty impact social valuation and policy?", Working Paper, University of Chicago.

Barreto, L. and R. Kemp (2008), "Inclusion of technology diffusion in energy-systems models: Some gaps and needs", *Journal of Cleaner Production* 16(1): 95–S101.

Barro, R.J. (2006), "Rare disasters and asset markets in the twentieth century", *Quarterly Journal of Economics* 121: 823-866.

Barro, R.J. and T. Jin (2011), "On the Size Distribution of Macroeconomic Disasters", *Econometrica* 79(5): 1567-1589.

Batten, S., R. Sowerbutts, and M. Tanaka (2016), "Let's Talk About the Weather: The Impact of Climate Change on Central Banks", Bank of England Working Paper 603 (https://ssrn.com/abstract=2783753).

Battiston, S. (2019), "The importance of being forward-looking: Managing financial stability in the face of climate risk", *Banque de France Financial Stability Review* 23: 39–48.

Battiston, S., A. Mandel, I. Monasterolo, F. Schütze, and G. Visentin (2017), "A climate stress-Test of the financial system", Nature Climate Change, 7(4): 283–288.

Behncke, H. (2000), "Optimal control of deterministic epidemics", *Optimal Control Applications and Methods* 21(6): 269-285.

Bollen, N.P. (2007), "Mutual fund attributes and investor behavior", *Journal of Financial and Quantitative Analysis* 42: 683-708.

Bolton, P. and J. Farrell (1990), "Decentralization, Duplication, and Delay", *Journal of Political Economy* 98(4): 803-26.

Bolton, P. and M. Kacperczyk (2020a), "Do investors care about carbon risk?", *Journal of Financial Economics*, forthcoming.

Bolton, P. and M. Kacperczyk (2020b), "Global pricing of carbon-transition risk", Working Paper, Imperial College.

Bolton, P. and M. Kacperczyk (2020c), "Signaling through carbon disclosure", Working Paper, Imperial College.

Bolton, P. and M. Kacperczyk (2020d), "Carbon premium around the world", Working Paper, Imperial College.

Bolton, P., S. Cecchetti, J.P. Danthine, and X. Vives (2019), *Sound at Last? Assessing a Decade of Financial Regulation*, Future of Banking 1, CEPR.

Bolton, P., M. Despres, L. Pereira da Silva, F. Samama, and R. Svartzman (2020a), *The green swan: Central banking and financial stability in the age of climate change*, Bank of International Settlements and Banque de France.

Bolton, P., M. Despres, L. Pereira da Silva, F. Samama, and R. Svartzman (2020b), "Green Swans: Central banks in the age of climate related risks", *Banque de France Bulletin* 229(8).

Bolton, P., T. Li, E. Ravina, and H. Rosenthal (2020c), "Investor ideology", *Journal of Financial Economics* 137: 320-352.

Broccardo, E., O. Hart, L. Zingales (2020), "Exit vs. voice", Working Paper, University of Chicago.

Brothers, W. (2020), "A Timeline of Covid-19 Vaccine Development", *Biospace*, 3 December (www.biospace.com/article/a-timeline-of-covid-19-vaccine-development/).

Burckart, W. and S. Lydenberg (2021), *21st Century Investing: Redirecting Financial Strategies to Drive Systems Change*, Berrett-Koehler Publishers

Burke, M., S.M. Hsiang, and E. Miguel (2015), "Global non-linear effect of temperature on economic production", *Nature* 527(7577): 235-239.

Cahen-Fourot, L., E. Campiglio, E. Dawkins, A. Godin, and E. Kemp-Benedict (2019), "Capital stranding cascades: The impact of decarbonisation on productive asset utilisation", Ecological Economic Papers 6854, WU Vienna University of Economics and Business

Cantillon, E. and A. Slechten (2018), "Information aggregation in emissions markets with abatement", CEPR Discussion Paper 13343

Capra, F. and P.L. Luisi (2014), *The systems view of life. A unifying vision*, Cambridge University Press.

Carbon Brief (2018), "How 'integrated assessment models' are used to study climate change" (www.carbonbrief.org/qa-how-integrated-assessment-models-are-used-to-study-climate-change).

Carletti, E., S. Claessens, A. Fatás, and X. Vives (2020), *The Bank Business Model in the Post-Covid-19 World*, Future of Banking 2, CEPR.

Carney, M. (2015), "Breaking the tragedy of the horizon – climate change and financial stability", Speech at Lloyd's of London (www.bis.org/review/r151009a.pdf)

Carney, M. (2016), "Resolving the climate paradox", Arthur Burns Memorial Lecture, Berlin (www.bis.org/review/r160926 h.pdf).

Chang, Y.C., H. Hong, and L. Liskovich (2015), "Regression discontinuity and the price effects of stock market indexing", *Review of Financial Studies* 28(1): 212-246.

Climate Bonds Initiative (2020), *Green Bonds: Global State of the Market 2019* (www.climatebonds.net/files/reports/cbi_sotm_2019_vol1_04d.pdf).

Cochrane, J. (2020), "Outside the box: a heretical view of stimulative policy, the role of central banks, and monetary-fiscal interactions" (www.ecb.europa.eu/pub/conferences/html/20201019_conferenceonmonetarypolicy.en.html).

CRS – Congressional Research Service (2021), "Operation Warp Speed contracts for Covid-19 vaccines and ancillary vaccination materials", Congressional Research Service Insight, 1 March (https://crsreports.congress.gov/product/pdf/IN/IN11560).

Cruz, J. L. and E. Rossi-Hansberg (2020), "The Geography of Global Warming", Princeton University Working Paper

Curran, P., N. Robins, and N. Stern (2019), "Unlocking the strategic economic opportunity of clean and inclusive growth", *Banque de France Financial Stability Review* 23: 29–38.

Daniel, K.D., R.B. Litterman, and G. Wagner (2019), "Declining CO2 price paths", *Proceedings of the National Academy of Sciences* 116(42): 20886-20891.

de Pee, A., D. Pinner, O. Roelofsen, K. Somers, E. Speelman, and M. Witteveen (2018), *Decarbonization of industrial sectors: the next frontier*, McKinsey Sustainability Report, Mckinsey and Company.

Dell, M., B.F. Jones, and B.A. Olken (2014), "What do we learn from the weather? The new climate-economy literature", *Journal of Economic Literature* 52(3): 740-98.

DNB and PBL– De Nederlandsche Bank and Netherlands Environmental Assessment Agency (2020), *Indebted to nature: Exploring biodiversity risks for the Dutch financial sector* (www.dnb.nl/media/4c3fqawd/indebted-to-nature.pdf).

Duffie, D. (2001), *Dynamic Asset Pricing Theory*, Princeton University Press.

Dureau, J., K. Kalogeropoulos, and M. Baguelin (2013), "Capturing the time-varying drivers of an epidemic using stochastic dynamical systems", *Biostatistics* 14(3): 541-555.

EBA – European Banking Authority (2019), "2020 EU-wide stress test - methodological note".

ECB – European Central Bank (2020a), "Guide on climate-related and environmental risks: Supervisory expectations relating to risk management and disclosure".

ECB (2020b), "ECB to accept sustainability-linked bonds as collateral. European Central Bank," Press release, (www.ecb.europa.eu/press/pr/date/2020/html/ecb.pr200922~482e4a5a90.en.html).

Eccles, R., S. Klimenko (2019), "The investor revolution", *Harvard Business Review* ,May-June: 106-116.

Eccles, R.G. and C. Mayer (2021), "Can a Tiny Hedge Fund Push ExxonMobil Towards Sustainability?", *Harvard Business Review.*

Eccles R., A. Mastagni, and K. Jenkinson (2021), "An Introduction to Activist Stewardship", Harvard Law School Forum on Corporate Governance (https://corpgov.law.harvard.edu/2021/03/01/an-introduction-to-activist-stewardship/).

EIOPA – European Insurance and Occupational Pensions Authority (2019), *Methodological principles of insurance stress testing* (https://www.eiopa.europa.eu/sites/default/files/publications/consultations/methodological_principle_of_insurance_stress_testing_1.pdf).

Engle, R.F., S. Giglio, B. Kelly, H. Lee, and J. Stroebel (2020), "Hedging climate change news", *Review of Financial Studies* 33(3).

Epstein, L.G. and S.E. Zin (1989), "Substitution, risk aversion, and the temporal behavior of consumption", *Econometrica* 57(4): 937-969.

Espagne, E. (2018), "Money, finance and climate: The elusive quest for a truly integrated assessment model", *Comparative Economic Studies* 60(1): 131–143.

ESRB – European Systemic Risk Board (2016), *Too late, too sudden: Transition to a low-carbon economy and systemic risk*, ESRB Reports of the Advisory Scientific Committee.

European Commission (2019), "The European Green Deal", COM(2019) 640 final, Brussels, 11 December.

Federal Reserve Board (2020), *Financial Stability Report*, 15 May.

Financial Stability Board (2020), "The Implications of Climate Change for Financial Stability", November (www.fsb.org/wp-content/uploads/P231120.pdf).

Finansinspektionen (2016), *Climate change and financial stability* (www.fi.se/contentassets/df3648b6cbf448ca822d3469eca4dea3/klimat-finansiell-stabilitet-mars2016_eng.pdf).

Flammer, C. (2020), "Corporate green bonds", *Journal of Financial Economics*, forthcoming.

Flammer, C., M.W. Toffel, K. Viswanathan (2020), "Shareholder activism and firms' voluntary disclosure of climate change risks", Working Paper, Boston University.

Flodén, M. (2019), "Monetary policy in a changing world", Speech at the Örebro University and Kommuninvest, Örebro (www.bis.org/review/r191113c.pdf).

Gates, B. (2021), *How to Avoid a Climate Disaster: The Solutions We Have and the Breakthroughs We Need*, Knopf.

Geels, F. W., B. Elzen, and K. Green (2004), "General introduction: System Innovation and Transitions to Sustainability" in B. Elzen, F. W. Geels, and K. Green (Eds.), *System Innovation and the Transition to Sustainability - Theory, Evidence and Policy*, 19–47, Edward Elgar.

Geels, F. W., F. Berkhout, and D.P. van Vuuren (2016), "Bridging analytical approaches for low-carbon transitions", *Nature Climate Change* 6(6): 576–583.

Geels, F. W., B.K. Sovacool, T. Schwanen, and S. Sorrell (2017), "The socio-technical dynamics of low-carbon transitions", *Joule* 1(3): 463–479.

Giglio, S., B.T. Kelly, and J. Stroebel (2020), "Climate Finance", National Bureau of Economic Research Working paper 28226.

Giglio, S., M. Maggiori, J. Stroebel, and A. Weber (2021), "Climate change and long-run discount rates: Evidence from real estate", *Review of Financial Studies*, forthcoming.

Golosov, M., J. Hassler, P. Krusell, and A. Tsyvinski (2014), "Optimal taxes on fossil fuel in general equilibrium", *Econometrica* 82(1): 41-88.

Gore, A. (2006) *An Inconvenient Truth: The Planetary Emergency of Global Warming and What We Can Do About It*, Rodale Inc.

Gorte J., J. Hale, B. McGannon, G. Dyer, B. Gridley, B. Rees, and J. Zinner (2020), "Public Comments Overwhelmingly Oppose Proposed Rule Limiting the Use of ESG in ERISA Retirement Plans", The Forum for Sustainable and Responsible Investment.

Gray, A., D. Greenhalgh, L. Hu, X. Mao, and J. Pan (2011), "A stochastic differential equation SIS epidemic model", *SIAM Journal on Applied Mathematics* 71(3): 876-902.

Grinsted, A., P. Ditlevsen, and J.H. Christensen (2019), "Normalized US hurricane damage estimates using area of total destruction, 1900-2018", *Proceedings of the National Academy of Sciences* 116(48): 23942-23946.

Hartzmark, S.M., and A.B. Sussman (2019), "Do investors value sustainability? A natural experiment examining ranking and fund flows", *Journal of Finance* 74: 2789–2837.

Hatchett, R.J., C.E. Mecher, and M. Lipsitch (2007), "Public health interventions and epidemic intensity during the 1918 influenza pandemic", *Proceedings of the National Academy of Sciences* 104(18): 7582--7587.

Hayek, F.A. (1945), "The Use of Knowledge in Society", *The American Economic Review* 35(4): 519-530.

Heal G. (2017), "The Economics of the Climate", *Journal of Economic Literature* 55(3): 1046–1063.

Heinkel, R., A. Kraus, and J. Zechner (2001), "The effect of green investment on corporate behavior", *Journal of Financial and Quantitative Analysis* 36(4): 431-449.

Hepburn, C., B. O'Callaghan, S. Stern, J. Stiglitz, and D. Zenghelis (2020a), "Will Covid-19 fiscal recovery packages accelerate or retard progress on climate change?", *Oxford Review of Economic Policy* 36(Supplement_1).

Hepburn, C., J. Stiglitz, and N. Stern (2020b), "Carbon pricing," *European Economic Review*, 127.

HM Treasury (2021), *The Economics of Biodiversity: The Dasgupta Review*, Final Report of the Independent Review on the Economics of Biodiversity led by Professor Sir Partha Dasgupta (www.gov.uk/government/publications/final-report-the-economics-of-biodiversity-the-dasgupta-review).

Hong, H. and M. Kacperczyk (2009), "The price of sin: The effects of social norms on markets", *Journal of Financial Economics* 93(1): 15-36.

Hong, H. and L. Kostovetsky (2012), "Red and blue investing: Values and finance", *Journal of Financial Economics* 103: 1-19.

Hong, H., F.W. Li, and J. Xu (2019), "Climate risks and market efficiency", *Journal of Econometrics* 208(1): 265-281.

Hong, H., N. Wang, and J. Yang (2020a), "Implications of stochastic transmission rates for managing pandemic risks", *Review of Financial Studies*, forthcoming.

Hong, H., N. Wang, and J. Yang (2020b), "Mitigating disaster risks in the age of climate change", National Bureau of Economic Research Working Paper.

Hong, H., N. Wang, and J. Yang (2021a), "Welfare effects of sustainable finance", National Bureau of Economic Research Working Paper.

Hong, H., J. Kubik, N. Wang, X. Xu, and J. Yang (2021b), "Pandemics, vaccines and corporate earnings", National Bureau of Economic Research Working Paper No. 27829.

Hsiang, S.M. and A.S. Jina (2014), "The causal effect of environmental catastrophe on long-run economic growth: Evidence from 6,700 cyclones", National Bureau of Economic Research Working Paper No. 20352.

IAIS – International Association of Insurance Supervisors (2018), *Issues paper on climate change risks to the insurance sector*, International Association of Insurance Supervisors & Bank for International Settlements.

IEA – International Energy Agency (2020), *Energy Technology Perspectives 2020* (www.iea.org/reports/energy-technology-perspectives-2020).

IEA (2021), *Global Energy Review: CO2 Emissions in 2020*.

Imai, N., A. Cori, I. Dorigatti, M. Baguelin, C.A. Donnelly, S. Riley, and N.M. Ferguson (2020), *Report 3: transmissibility of 2019-nCoV*, Imperial College London.

IPCC – Intergovernmental Panel on Climate Change (2014), *Climate change 2014: Synthesis report. Contribution of working groups I, II and III to the fifth assessment report of the intergovernmental panel on climate change.*

IPCC (2018), "Summary for policymakers", in *Global warming of 1.5°C, an IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change.*

IRENA – International Renewable Energy Agency (2019), *A new world - the geopolitics of the energy transformation*.

Issler, P., R. Stanton, C. Vergara, and N. Wallace (2020), "Mortgage markets with climate-change risk: Evidence from wildfires in California", Working Paper (https://ssrn.com/abstract=3511843).

Jackson, T. (2017), *Prosperity without growth*, Routledge.

Johnsson, F., J. Kjärstad, and J. Rootzén (2019), "The threat to climate change mitigation posed by the abundance of fossil fuels", *Climate Policy* 19(2): 258–274.

Kacperczyk, M., C. Sialm, and L. Zheng (2005), "On the industry concentration of actively managed U.S. equity mutual funds", *Journal of Finance* 60: 1983-2012.

Kacperczyk, M., S. van Nieuwerburgh, and L. Veldkamp (2016), "A rational theory of mutual funds' attention allocation", *Econometrica*, 84(2): 571-626.

Kacperczyk, M., J. Nosal, and S. Sundaresan (2020), "Market power and price informativeness", Working Paper, Imperial College.

Kacperczyk, M., S. Sundaresan, and T. Wang (2021), "Do foreign institutional investors improve price efficiency?", *Review of Financial Studies* 34: 1317-1367.

Kelley, C. P., S. Mohtadi, M.A. Cane, R. Seager, and Y. Kushnir (2015), "Climate change in the fertile crescent and implications of the recent Syrian drought", *Proceedings of the National Academy of Sciences* 112(11): 3241–3246.

Kermack, W.O. and A.G. McKendrick (1927), "A contribution to the mathematical theory of epidemics", *Proceedings of the Royal Society of London. Series A, Containing Papers of a Mathematical and Physical Character* 115(772): 700-721.

Khasnis, A.A. and M.D. Nettleman (2005), "Global warming and infectious disease", *Archives of Medical Research* 36(6): 689-696.

Koijen, R.S. and M. Yogo (2019), "A demand system approach to asset pricing", *Journal of Political Economy* 127(4): 1475-1515.

Kossin, J.P., K.R. Knapp, T.L. Olander, and C.S. Velden (2020), "Global increase in major tropical cyclone exceedance probability over the past four decades", *Proceedings of the National Academy of Sciences* 117(22): 11975-11980.

Kozlowski, J., L. Veldkamp, and V. Venkateswaran (2020), "Scarring body and mind: The long-term belief-scarring effects of Covid-19", National Bureau of Economic Research Working Paper No. 27439.

Krueger, P., Z. Sautner, and L. Starks (2020), "The importance of climate risks for institutional investors", *Review of Financial Studies* 33: 1067-1111.

Kucharski, A.J., T.W. Russell, C. Diamond, Y. Liu, J. Edmunds, S. Funk, R.M. Eggo, F. Sun, M. Jit, J.D. Munday, and N. Davies (2020), "Early dynamics of transmission and control of Covid-19: a mathematical modelling study", *The Lancet Infectious Diseases* 20(5): 553-558.

Lamperti, F., I. Monasterolo, and A. Roventini (2019), "Climate risks, economics and finance: Insights from complex systems", in L. Urbani (ed.), *The systemic turn in human and natural sciences*, 97–119, Springer.

Lawhon, M. and J.T. Murphy (2011), "Socio-technical regimes and sustainability transitions: Insights from political ecology", *Progress in Human Geography* 36(3): 354–378.

Legendre, M., A. Lartigue, L. Bertaux, S. Jeudy, and J. Bartoli (2015), "In-depth study of mollivirus sibericum giant virus", *Proceedings of the National Academy of Sciences* 112(38): 5327–5335.

Lenton, T. M., J. Rockström, O. Gaffney, S. Rahmstorf, K. Richardson, W. Steffen, and H.J. Schellnhuber (2019), "Climate tipping points— too risky to bet against", *Nature* 575: 592–595.

Litterman, R. (2010), "Tilt of Benchmarks", in Bolton, P., F. Samama, and J. Stiglitz (eds.) *Sovereign Wealth Funds and Long-Term Investing*, Columbia University Press.

Llavador, H., J. Roemer, and J. Silvestre (2015), *Sustainability for a Warming Planet,* Harvard University Press.

Lukomnik, J. and J.P. Hawley (2021), *Moving Beyond Modern Portfolio Theory: Investing That Matters,* Routledge.

Matos, P. (2020), "ESG and Responsible Institutional Investing Around the World: A Critical Review", CFA Institute Working Paper.

Matikainen, S., E. Campiglio, and D. Zenghelis (2017), "The climate impact of quantitative easing", Grantham Institute Policy Paper.

Mattioli, G., C. Roberts, J. Steinberger, and A. Brown (2020), "The political economy of car dependence of car dependence: A systems of provision approach", *Energy Research and Social Science* 66: 1014-86.

Mayer, C. (2013), *Firm Commitment: Why the Corporation Is Failing Us and How to Restore Trust In It*, Oxford University Press.

McGlade, C. and P. Ekins (2015), "The geographical distribution of fossil fuels unused when limiting global warming to 2°C", *Nature* 517: 187-190.

McNamara, K.E., R. Bronen, N. Fernando, and S. Klepp (2018), "The complex decision-making of climate-induced relocation: Adaptation and loss and damage", *Climate Policy* 18(1): 111-117.

Mercure, J. F., H. Pollitt, A,M. Bassi, J.E. Viñuales, and N.R. Edwards (2016), "Modelling complex systems of heterogeneous agents to better design sustainability transitions policy", *Global Environmental Change* 37: 102-115.

Mercure, J. F., F. Knobloch, H. Pollitt, L. Paroussos, S.S. Scrieciu, and R. Lewney (2019), "Modelling innovation and the macroeconomics of low-carbon transitions: Theory, perspectives and practical use", *Climate Policy* 19(8): 1019-1037.

Merton, R.C. (1987), "A simple model of capital market equilibrium with incomplete information", *Journal of Finance* 42(3): 483-510.

Metcalf, G., and J. Stock (2020), "The macroeconomic impact of Europe's carbon taxes", National Bureau of Economic Research Working Paper No. 27488.

Monasterolo, I., A. Roventini, and T. Foxon (2019), "Uncertainty of climate policies and implications for economics and finance: An evolutionary economics approach", *Ecological Economics* 163(C): 177–182.

Murfin, J. and M. Spiegel (2020), "Is the risk of sea level rise capitalized in residential real estate?", *The Review of Financial Studies* 33(3): 1217-1255.

Naidoo, C.P. (2020), "Relating financial systems to sustainability transitions: Challenges, demands and design features", *Environmental Innovation and Societal Transitions* 36: 270–290.

National Academy of Sciences (2016), *Attribution of extreme weather events in the context of climate change*, The National Academies Press.

NGFS – Network for Greening the Financial System (2018), *NGFS first progress report* (www.ngfs.net/en/first-progressreport).

NGFS (2019a), *NGFS first comprehensive report. A call for action - climate change as a source of financial risk* (www.ngfs.net/en/first-comprehensive-report-call-action).

NGFS (2019b), *Macroeconomic and financial stability: Implications of climate change*, NGFS technical supplement to the first comprehensive report (www.ngfs.net/en/first-comprehensive-report-callaction)

NGFS (2020), *NGFS climate scenarios for central banks and supervisors* (www.ngfs.net/sites/default/files/medias/documents/820184_ngfs_scenarios_final_version_v6.pdf)

NGFS (2021), *Adapting central bank operations to a hotter world: Reviewing some options* (www.ngfs.net/en/adapting-central-bank-operations-hotter-world-reviewing-some-options)

Nordhaus, W.D. (1975), "Strategies for the Control of Carbon Dioxide", Cowles Foundation Discussion Paper.

Nordhaus, W.D. (1977), "Economic Growth and Climate: The Carbon Dioxide Problem", *American Economic Review* 67(1): 341-346.

Nordhaus, W.D. (2008), *A question of balance: Economic modelling of global warming*, Yale University Press.

Nordhaus, W.D. (2017), "Revisiting the social cost of carbon", *Proceedings of the National Academy of Sciences* 114(7): 1518-1523.

OECD – Organisation for Economic Co-operation and Development (2019), *Biodiversity: Finance and the Economic and Business Case for Action* (www.oecd.org/env/resources/biodiversity/biodiversity-finance-and-the-economic-and-business-case-for-action.htm).

Oehmke, M. and M. Opp (2020), "A theory of socially responsible investment", Working Paper, London School of Economics.

Pastor, L., R.F. Stambaugh, and L.A. Taylor (2020), "Sustainable investing in equilibrium", *Journal of Financial Economics*, forthcoming.

Pastor, L. and B. Vorsatz (2020), "Mutual fund performance and flows during the Covid-19 crisis", *Review of Asset Pricing Studies* 10: 791-833.

Pedersen, L.H., S. Fitzgibbons, and L. Pomorski (2020), "Responsible investing: The ESG-efficient frontier", *Journal of Financial Economics*, forthcoming.

Pereira da Silva, L.A. (2019), "Research on climate-related risks and financial stability: An epistemological break?", based on remarks at the Conference of the Central Banks and Supervisors Network for Greening the Financial System (NGFS), Paris, (www.bis.org/speeches/sp190523.htm).

Phelps, E.S., A.A. Alchian, C. C. Holt et al. (1969), *Microeconomic Foundations of Employment and Inflation Theory*, Norton.

Pindyck, R. S., and N. Wang (2013), "The economic and policy consequences of catastrophes", *American Economic Journal: Economic Policy* 5(4): 306-339.

PRA – Prudential Regulation Authority (2019), "Life insurance stress test 2019 - scenario specification, guidelines and Instructions", Bank of England Prudential Regulation Authority (www.bankofengland.co.uk/-/media/boe/files/prudentialregulation/letter/2019/life-insurance-stress-test-2019-scenario-specification-guidelines-and-instructions.pdf).

Quigley, E. (2019), "Universal Ownership in the Anthropocene", Working Paper (https://ssrn.com/abstract=3457205 or http://dx.doi.org/10.2139/ssrn.3457205).

Ramsey, F.P. (1928), "A Mathematical Theory of Saving", *The Economic Journal* 38(152): 543-559.

Regelink, M., H.J. Reinders, M. Vleeschhouwer, and I. van de Wiel (2017), *Waterproof? An exploration of climate-related risks for the Dutch financial sector*, De Nederlandsche Bank.

Ripple, W. J., C. Wolf, T.M. Newsome, M. Galetti, M. Alamgir, E. Crist, M.I. Mahmoud, W.F. Laurance, and 15,364 scientist signatories from 184 countries (2017), "World scientists' warning to humanity: A second notice", *BioScience* 67(12,1): 1026–1028.

Rogelj, J., D. Shindell, K. Jiang, S. Fifita, P. Forster, V. Ginzburg, C. Handa, H. Kheshgi, S. Kobayashi, E. Kriegler, L. Mundaca, R. Séférian, and M.V. Vilariño (2018), "Mitigation Pathways Compatible with 1.5°C in the Context of Sustainable Development", in *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty,* IPCC.

Rogoff, K. (1985), "The Optimal Degree of Commitment to an Intermediate Monetary Target", *Quarterly Journal of Economics* 100(4): 1169–1189.

Schlenker, W. and M.J. Roberts (2009), "Nonlinear temperature effects indicate severe damages to US crop yields under climate change", *Proceedings of the National Academy of Sciences* 106(37): 15594-15598.

Schmelz, W.J., G. Hochman, and K.G. Miller (2020), "Total cost of carbon capture and storage implemented at a regional scale: northeastern and midwestern United States", *Interface Focus* 10(5): 20190065.

Schroeder A. J., J.J. Gourley, J. Hardy, J.J. Henderson, P. Parhi, V. Rahmani, K.A. Reed, R.S. Schumacher, B.K. Smith, M.J. Taraldsen (2016), "The development of a flash flood severity index", *Journal of Hydrology* 541: 523–532.

Semieniuk, G., E. Campiglio, J.-F. Mercure, U. Volz, and N.R. Edwards (2020), "Low-carbon transition risks for finance", *WIREs Climate Change* 12(1).

Serafeim, G (2020), "Social-Impact Efforts That Create Real Value", *Harvard Business Review.*

Shleifer, A. (1986), “Do demand curves for stocks slope down?”, *Journal of Finance* 41(3): 579-590.

Starks, L. T., P. Venkat, and Q. Zhu (2017), “Corporate ESG Profiles and Investor Horizons”, Working Paper (https://ssrn.com/abstract=3049943).

Steffen, W., J. Rockström, K. Richardson, T.M. Lenton, C. Folke, D. Liverman, C.P. Summerhayes, A.D. Barnosky, S.E. Cornell, M. Crucifix, and J.F. Donges (2018), “Trajectories of the earth system in the Anthropocene”, *Proceedings of the National Academy of Sciences* 115(33): 8252–8259.

Stern, N. (2006), *The Economics of Climate Change: The Stern Review*, Cambridge University Press.

Stern, N. (2016), “Economics: Current climate models are grossly misleading,” *Nature* 530(7591): 407–409.

Svartzman, R., D. Dron, and E. Espagne (2019), “From ecological macroeconomics to a theory of endogenous money for a finite planet”, *Ecological Economics* 162: 108–120.

Svartzman, R., P. Bolton, M. Despres, L.A. Pereira Da Silva, and F. Samama (2020), “Central banks, financial stability and policy coordination in the age of climate uncertainty: a three-layered analytical and operational framework”, *Climate Policy (*DOI: 10.1080/14693062.2020.1862743).

Taleb, N. (2007), *The black swan: The impact of the highly improbable*, Penguin Random House.

Taylor, C.A., C. Boulos, and D. Almond (2020), “Livestock plants and Covid-19 transmission”, *Proceedings of the National Academy of Sciences* 117(50): 31706-31715.

TCFD – Task Force on Climate-Realted Financial Disclosures (2017), “The use of scenario analysis in disclosure of climate-related risks and opportunities” (www.fsb-tcfd.org/wp-content/uploads/2017/06/FINAL-TCFD-Technical-Supplement-062917.pdf).

Tirole, J. (2019), “Institutional and economic challenges for central banking,” in *Monetary policy: the challenges ahead*, European Central Bank (www.ecb.europa.eu/pub/pdf/other/ecb.20191217_Monetary_policy_the_challenges_ahead~2cac5a564e.en.pdf).

UNFCCC – United Nations Climate Change (2021), *NDC Synthesis Report* (https://unfccc.int/process-and-meetings/the-paris-agreement/nationally-determined-contributions-ndcs/nationally-determined-contributions-ndcs/ndc-synthesis-report).

Van Nieuwerburgh, S. and L. Veldkamp (2010), “Information acquisition and under-diversification”, *Review of Economic Studies* 77(2): 779-805.

Vermeulen, R., E. Schets, M. Lohuis, B. Kölbl, D.J. Jansen, and W. Heeringa (2018), "An energy transition risk stress test for the financial system of the Netherlands", De Nederlandsche Bank Occasional Studies (www.dnb.nl/media/pdnpdalc/201810_nr-_7_-2018-_an_energy_transition_risk_stress_test_for_the_financial_system_of_the_netherlands.pdf)

Vermeulen, R., E. Schets, M. Lohuis, B. Kölbl, D.J. Jansen, and W. Heeringa (2019), "The heat is on: A framework measuring financial stress under disruptive energy transition scenarios," De Nederlandsche Bank Working Paper 625 (www.dnb.nl/media/jpuj1mgt/working-paper-no-625_tcm47-382291.pdf).

Vives, X. (2011), "Strategic Supply Function Competition with Private information", *Econometrica* 79(6): 1919-1966.

Weise, K. (2020), "Ahead of the Pack, How Microsoft Told Workers to Stay Home", *New York Times*, March 15.

Weitzman, M.L. (2009), "On modelling and interpreting the economics of catastrophic climate change", *Review of Economics and Statistics* 91(1): 1–19.

Weitzman, M.L. (2011), "Fat-tailed uncertainty in the economics of catastrophic climate change", *Review of Environmental Economics and Policy* 5(2): 275–292.

WHO (2021), *Rethinking policy priorities in the light of pandemics: a call to action* (www.euro.who.int/en/health-topics/health-policy/european-programme-of-work/pan-european-commission-on-health-and-sustainable-development/multimedia/rethinking-policy-priorities-in-the-light-of-pandemics-a-call-to-action).

Wickwire, K. (1977), "Mathematical models for the control of pests and infectious diseases: a survey", *Theoretical Population Biology* 11(2): 182-238.

World Bank (2020), *State and trends of carbon pricing 2020*.

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The Covid-19 pandemic has exposed severe vulnerabilities in the global financial system, and serves as a cautionary tale for the potentially devastating effects that future natural disasters and climate change could cause to the world economy. The question of whether society is adequately prepared and what measures can be put in place to mitigate these risks has never been more pertinent.

This CEPR/IESE report, the third report in the series on *The Future of Banking*, part of the Banking Initiative from the IESE Business School and supported by Citi, tests precisely how resilient the financial system is to natural disasters and discusses what can be done to make it more resilient. The report details how to reshape central bank policies to address climate-related risks, debates the role of asset managers in dealing with natural disasters and climate risk, and explains why mitigation is a form of self-insurance to limit the systemic risks of global warming.

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